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WATER-SUPPLY PAPER 253

WATER POWERS OF THE CASCADE RANGE

PART I.—SOUTHERN WASHINGTON

BY

JOHN C. STEVENS

PREPARED IN COOPERATION WITH THE STATE OF WASHINGTON

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WATER POWERS OF THE CASCADE RANGE.

PART I.—SOUTHERN WASHINGTON.[a]

By J. C. STEVENS.

INTRODUCTION.

Perhaps no area in the United States presents more favorable opportunities for water-power development than that traversed by the Cascade Range. The general elevation of the summit of the range is from 6,000 to 8,000 feet, and many of its peaks extend into the region of eternal snow. Among these peaks are Mount Baker (10,827 feet), Mount Rainier (14,363 feet), Mount St. Helens (9,750 feet), Mount Adams (12,307 feet), Mount Hood (11,225 feet), Mount Jefferson (10,300 feet), Mount McLaughlin or Pitt (9,760 feet), and Mount Shasta (14,380 feet). The streams draining this range have steep slopes and are fed during the low-water period by the many snow banks and glaciers that mantle the high peaks or by the liberal supplies of ground water. The precipitation on the area is abundant, although its distribution is by no means uniform. The streams possess the requisite properties of water-power development—rapid fall, abundant water, and comparative uniformity of flow; and the almost unlimited resources of timber, mines, and soil, as yet hardly touched, afford a promising market for these water powers and fixes for them a high potential value.

The primary source of rainfall in the Pacific States is evaporation from the Pacific Ocean, the water vapor being carried over the land by prevailing westerly winds. Whenever the moisture-laden air is cooled below the point of saturation, rain falls, and no precipitation can occur unless the air is thus cooled. The temperatures over the ocean are not nearly so variable as those over the land. In summer the land is relatively much warmer than the ocean, while in winter the reverse is true. Hence the general tendency is for the water vapor to be carried eastward over the mountains in summer and to

[a] This paper is the first of a proposed series dealing with the water powers of the streams flowing from the Cascade Range in Washington and Oregon. It is the intention to gather sufficient data each season to constitute the material for one unit of the report.

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be precipitated on them in winter. Thus we have the wet and dry seasons.

When the air in its eastward course encounters the western slope of the mountain ranges it is deflected upward into regions of diminished pressure. The resulting adiabatic expansion cools the air and the water vapor is precipitated. Thus the rainfall on the windward side of the range is much greater than on the leeward side, while the maximum rainfall probably occurs just over the divide. The summit of the Coast Range receives about 150 inches of rainfall in a year and the Cascade Range about 100 inches. Only about 5 per cent of this falls during the summer months, so that during this period the streams draw upon water stored in the ground and in snow banks and glaciers during the previous winter. The low-water period therefore occurs just before the fall rains begin.

The area treated in this paper comprises the drainage basins of Klickitat, White Salmon, Little White Salmon, Lewis, and Toutle rivers and is located in the southern extremity of the Cascade Range in Washington. The broad crest of this portion of the divide lies wholly within the Columbia and Rainier national forests, within which all streams of the region have their sources.

Special investigations made on these streams during the season of 1909 form the basis for this report. Each of the streams investigated is considered in detail. Descriptions of the several drainage areas are given, together with profiles of the streams and principal tributaries,[a] discharge data, and a detailed compilation of the water powers capable of being developed at the average minimum stage. The report must be considered rather as an inventory of the latent power resources of this section than as an engineering report on feasible power projects. It is, however, based on engineering principles, and the present practices of water-power development have been given due consideration.

The field investigations were made by two parties of four men each, which were in the field from July 1 to October 1. One party, in charge of H. D. McGlashan, junior engineer, United States Geological Survey, made the surveys of Klickitat, White Salmon, and Little White Salmon rivers. The other, in charge of C. W. Harris, instructor in hydraulics, University of Washington, made the surveys of Lewis and Toutle rivers. Warren O. Harmon, Charles Leidl, F. W. Whalley, and C. F. Holmes, students at Washington State College, were employed as rodmen. A map and a profile of each stream were made and data were gathered as to the discharges at critical points in each drainage area. From these data the undeveloped water powers have been computed. Except for a

[a] Plans and profiles of each river surveyed are bound on stubs at the end of this volume.

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200-horsepower plant at Husum, on White Salmon River, there are no developed powers on any of the above-named streams.

In presenting the power statistics the average minimum flow of the streams has been used. The average minimum may be defined as the mean discharge for the lowest week in each year, averaged for a succession of years, say ten. The absolute minimum in a ten-year cycle might be as low as a third or a fourth of the average minimum, but it would continue only for one or two days, possibly only for a few hours.

METHOD OF INVESTIGATION.

A brief outline of the plan followed in field work will convey some idea of the degree of accuracy obtained in the results.

Each party consisted of one chief, two rodmen, and one man as cook and packer, and was provided with four pack horses, two small tents, and the necessary camp equipment. The chief of party was also instrumentman.

All distances were determined by stadia and all elevations by vertical angles. Initial elevations were taken from railroad bench marks and reduced to United States Geological Survey datum by known equations. The upper portion of Klickitat River is included in the Mount Adams quadrangle, and elevations were adjusted to agree with a line of United States Geological Survey bench marks following the upper course of the stream. The datum of the survey was taken from the Spokane, Portland and Seattle Railway crossing of Klickitat River near Lyle.

Klickitat and Lewis river surveys were made by azimuth control, meridian being obtained by direct solar observations. On the other streams magnetic control was used, permitting much more rapid but not so accurate work. In portions of the area where land surveys have been made frequent ties to section corners were possible; hence the necessity for refined control is not so great. If it were not for local variation in the vicinity of lava beds and basaltic areas magnetic control would have been used altogether.

The plan was to follow the river as closely as possible and take sufficient "shots" on the water surface to define the course of the streams with reference to land lines and determine the general grade of the water surface, small undulations of the water grade being disregarded. In many places it was impossible to follow the river closely on account of nearly vertical canyon walls, or dense underbrush, or both. In such places the survey followed the lines of least resistance, making side lines to the river at frequent intervals. In some portions an apparently impassable stretch was surveyed by wading up the stream, if not too deep, or by following the water's edge closely with a rodman on each side and wading across on riffles where necessary. The average run per day for all working days in

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the season was 1.5 miles for each party, but runs of 6 or 7 miles in a day were occasionally made.

At selected points gages were installed and discharge measurements made. Wherever a local resident was available he was employed to keep a daily record of gage heights. In this manner it was possible to determine the minimum flow for the season. Then by comparing the determined minimum flow for 1909 with that of other years on streams where longer records of discharge were available, some idea of the relative value of 1909 records in a cycle of years was obtained.

No systematic records of stream flow had previously been kept by the United States Geological Survey on any of the streams of this region, but through courtesy of certain power and irrigation companies and private individuals a few gage records, somewhat scattered and interrupted, and a few discharge measurements were made available. These data have been used for comparison, and those that appear in the report are published with the consent of the persons supplying the information.

The total cost of the report ready for publication is analyzed in the following table:

Cost of water-power investigations in Washington, 1909.

River.	River profiles and topography.	Gaging discharge.	Drafting and compiling.	Total cost.	Miles surveyed.	Cost per mile.
Klickitat	$1,060.65	$86.50	$228.43	$1,375.58	81.2	$16.94
White Salmon	543.13	15.35	96.22	654.70	34.2	19.14
Little White Salmon	141.73	7.67	22.79	172.19	8.1	21.26
Lewis	1,097.23	50.00	182.86	1,330.09	65.0	20.46
Toutle	557.11	16.35	167.67	741.13	59.6	12.43
	3,399.85	175.87	697.97	4,273.69	248.1	17.11
Per cent of total	80	4	16	100		

SUMMARY OF RESULTS.

Klickitat River leads all others in this region in opportunities for water-power development. Seventy-three miles of the main river were surveyed with a range of 3,255 feet elevation. The river next in importance is the White Salmon, with a fall of 2,660 feet in 32 miles. Lewis River was surveyed for 51 miles, in which distance a fall of 1,495 feet was found. Toutle River is 54 miles long, the entire length being mapped. It has a fall of 3,153 feet. Little White Salmon River is of secondary importance. The discharge is low, but the stream has a steep grade, a fall of 1,285 feet being found in the 8 miles surveyed.

The following table gives a summary of the data obtained during the season of 1909 in this region. The total horsepower for the average minimum discharge of the streams as surveyed is 386,500.

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Summary of water-power surveys.

Stream system.	Miles surveyed.	Total horsepower for average minimum discharge.
Klickitat	81.2	154,000
White Salmon	34.2	105,000
Little White Salmon	8.1	5,500
Lewis	65.0	78,000
Toutle	59.6	44,000
	248.1	386,500

It would probably be safe to add about 8,000 horsepower for small tributaries and portions of the main streams not surveyed, giving in round numbers 395,000 horsepower for the streams named above. The principal streams not surveyed in this region are Wind River, Washugal River, Salmon River, South Fork of Lewis River, Kalama River, South Fork of Toutle River, and Green River. The aggregate power on these streams at low stage is probably not over 30,000 horsepower, making a grand total for this entire area of 425,000 horsepower.

It has been estimated from very meager data that the total water power in the Columbia River basin will aggregate 10,500,000 horsepower at the average minimum stage of the rivers.[a] The possible water-power development of the region under discussion, therefore, is only 4 per cent of this total. At present the water-power plants in operation in the State of Washington have an aggregated rated capacity of about 81,000 horsepower, so that the possible development in this region is five times that already developed in the State.

COOPERATION AND ACKNOWLEDGMENTS.

In 1909 the legislature of Washington passed an act providing for state cooperation with the United States Geological Survey which reads in part as follows:

In order to complete the topographic map of the State of Washington, and for the purpose of making more extensive stream measurements and otherwise investigating and determining the water supply of the State, there is hereby appropriated the sum of thirty thousand dollars, for cooperation with those branches of the United States Geological Survey engaged in this work. This appropriation, however, shall be contingent upon, and not become available unless the United States Government apportion an equal amount to be expended for similar purposes within the State. The Board of Geological Survey is hereby authorized and directed to enter into such agreements with the Director of the United States Geological Survey, as will insure that the said surveys and investigations be carried on in the most economical manner and that the maps and data be available for the use of the public as quickly as possible.

[a] Rept. Nat. Conservation Comm., Senate Doc. 676, 60th Cong. 2d sess., p. 169.

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The money thus appropriated was met by an equal allotment from funds of the United States Geological Survey and divided, for the first year's work, as follows:

For topographic mapping:	
State	$10,000
Government	10,000
For water resources:	
State	5,000
Government	5,000

Expenditures for this report were made from the water-resources fund.

The State Board of Geological Survey, consisting of the governor, treasurer, secretary of state, and the presidents of the State University and State Agricultural College, represents the State in this cooperative work. The board elected Henry Landes, professor of geology at the State University, as state geologist and intrusted him with supervisory authority to represent the State in the details of these cooperative surveys. The field work was done and the report has been prepared by the United States Geological Survey.

The writer is indebted to Prof. Henry Landes, state geologist, for his hearty cooperation in all matters pertaining to the joint work in the State, of which the material gathered for this report is a part.

Acknowledgments are due to the following companies and individuals for heretofore unpublished stream-flow data and gage records and for cooperation in the maintenance of certain gaging stations: Portland Railway, Light, and Power Company, of Portland, Oreg.; William R. King, of Portland, Oreg., civil and hydraulic engineer; Klickitat Irrigation and Power Company, of Seattle, Wash.; H. L. Gilbert, of Portland, Oreg., civil and hydraulic engineer; Ham, Yearsley & Ryrie, of Spokane, Wash.

Acknowledgments are also due to Mr. Ralph Williamson, attorney for the United States Reclamation Service at North Yakima, for an abstract of the Washington laws relating to water filings.

CONDITIONS GOVERNING HYDRAULIC DEVELOPMENT.

From the standpoint of the public an answer to the question, "How much water power is there on a certain stream or in a certain territory?" is of great importance. In areas where great water powers are known to exist and public-service corporations are appropriating them as fast as or faster than a market for them grows, the interest of the public in their development becomes a paramount issue.

The long-distance transmission of electric energy has changed our perspective of this resource amazingly during the last ten years. A few years ago the use of water power was limited to the immediate

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locality where it was developed. Now a hydro-electric plant can serve the industrial and community needs of an area 200 miles or more from it. This fact makes water power a public utility. The natural laws that govern the development of hydro-electric powers and the social and industrial conditions that supply the market for them make consolidation and community of interest among those engaged in their operation inevitable. In the operation of power plants for public service it is of prime importance that continuity of service be assured. The natural conditions of stream flow make it almost impossible for a single plant depending on water power alone to insure continuous service. Hence the necessity that one company should operate several plants.

The requirements of power consumers are by no means uniform. They vary from hour to hour, from day to day, and with the seasons. This nonuniform consumption requires that a certain reserve be maintained at all times to meet "peak loads" during the day and for regular and extraordinary demands that arise from time to time. Hence even where one company operates several plants it is virtually required to maintain auxiliary steam plants to be used in connection with the water-power plants.

From the standpoint of the consumer also, whether an individual, a company, or a municipality, there is every advantage in having the sources of power under one administration. Efficiency in operation and economy in consumption therefore demand consolidation of interests. Such a consolidation, which makes for conservative and efficient use of the natural-power resources, should not be prevented. The public concern, therefore, must be aimed, not toward prevention of consolidation, but toward prevention of the harm to the public interest that might result from an unscrupulous administration of such a consolidation. The solution appears to lie in a wise legislative regulation of the manner in which power privileges shall be acquired and power plants maintained in order that the consumer shall be assured the necessary energy at a reasonable cost, consistent with a just and reasonable income on the investments by the power companies.

The factors that govern power development are three—(1) the volume of water available, (2) the fall through which this water can be utilized, (3) the market for the power when developed.

A project is feasible or not according as these factors are favorable. The market feature is, of course, independent of the other two and is subject to evolutionary laws. Therefore in a public inquiry such as that covered by this report it is necessary to consider only the physical features of discharge and fall, and to include all portions of a stream where such features make power development possible.

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Yet a consistent regard must be had for practicability of development, and some standard of comparison must be adopted.

In developing power plants it is profitable to install power units for a much larger amount of power than that represented by the minimum flow of the stream, for it is always necessary to have auxiliary steam plants which can be used to tide over a period of shortage of water and are called on for the peak loads. The interest, depreciation, and maintenance charges of a steam plant must be carried in conjunction with the fixed charges on the water-power plant. Hence the excess of power capacity which it is profitable to install over that afforded by the stream in extreme low water will depend on the relative cost of steam and water power and on the peculiarities of the particular market served. This excess may vary from 50 to 300 per cent.

In presenting general power statistics it is impossible to estimate this excess, and all that can be done is to state the power for the average minimum discharge of the stream and the known fall. The theoretical power thus obtained is arbitrarily reduced 30 per cent to represent "brake" horsepower, or the power that could probably be delivered to the turbine shafts. Where special studies are made the figure so derived can be increased or reduced according to the exigencies of the case.

WATER LAWS OF WASHINGTON.

The water laws of Washington relate chiefly to the use of water for irrigation, mining, logging, and municipal supplies. As water power may be applied to the generation and transmission of electric energy for pumping water for irrigation it is likely that the general provisions in the irrigation statutes would be applicable. There is no rigid line of demarcation between the uses of water for any beneficial purposes. Many of the provisions, by inference, apply to its use for water power, but no specific laws relating to hydro-electric developments have been enacted, except that of granting the right of eminent domain to "all corporations that are now or that may hereafter be incorporated under the laws of this State, or of any State or Territory of the United States and doing business in this State, for the purpose of conveying water by ditches, flumes, pipe lines, tunnels, or any other means for the utilization of water power." [a]

Any corporation authorized to do business in this State, which under the present laws of the State is authorized to condemn property for the purpose of generating and transmitting electrical power, * * * shall be deemed to be in respect of such purposes a public-service corporation. * * * Any such corporation shall have the right to sell electric light outside the limits of a municipality, and electric power both

[a] Pierce's Washington Code, 5155.

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inside and outside such limits to private consumers. * * * In exercising the power of eminent domain for public purposes it shall not be an objection thereto that a portion of the electric current generated will be applied to private purposes, provided the principal uses intended are public.[a]

The use of the waters of this State for irrigation, mining, and manufacturing purposes shall be deemed a public use.[b]

The following is a summary of present Washington statute law relating to water rights, abridged from a summary of irrigation law prepared by Ralph B. Williamson, attorney, United States Reclamation Service. In the footnote references in this summary the first number given refers to Ballinger's "Code and statutes," the second number to Pierce's "Code and statutes."

APPROPRIATION AND ACQUIRING OF THE RIGHT.

The right to use the waters of the State may be acquired by appropriation, the first in time being the first in right.[c] Written notice must be posted near the point of intended storage or diversion, stating the amount, purpose, places of use and means of diversion or storage, and such notice must be filed with the county auditor of the county where the notice is posted for record within ten days.[d] All amounts must be multiples or fractions of a cubic foot per second of time.[e]

Construction of works.—An appropriator must begin construction of works within three months after posting of notice if use is by storage; if by diversion within six months, and must diligently prosecute them to completion,[f] compliance with which gives priority as of time notice was posted.[g] It would seem that actual construction of a ditch gives right to unappropriated waters at the time construction is begun for irrigation[h] and pumps may be used when the land can not be reached by gravity flow.[i] Head-gates of existing canals may be changed or extended on streams where naturally made necessary, subject to existing rights.[j]

Filing of maps.—Within ninety days after construction or enlargement of a canal, there must be filed with the county clerk of the county in which the head-gate is located, a map showing location of head-gate, route of ditch, legal subdivisions crossed and names of owners, with statement showing location of works, depth, width, and grade of ditch, its carrying capacity and time of commencement of the work. Such filing will give priority from date of commencement of the work; if after ninety days, only from date of filing of the map.[k]

Seepage and springs.—Water from seepage and springs is governed by the general laws, provided that a man on whose land such waters first appear has prior right thereto;[l] and a man whose lands have been thus irrigated by seepage, has priority as of time of use of seepage, if by natural cause he must construct ditch to source of seepage to irrigate the lands.[m] Same rule applies to artesian wells.[n]

Change of use.—The purpose of appropriation may be changed to any beneficial use without losing the priority of the original appropriation.[o]

Transfer.—The right to the use of water is not made appurtenant to land but is allowed to be transferred, like property, by deed.[p]

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[a] Chapter 159, Session Laws, 1907.
[b] Constitution, Art. XXI.
[c] Sec. 4091; sec. 5131.
[d] Sec. 4092; sec. 5132.
[e] Sec. 4090; sec. 8942.
[f] Sec. 4093; sec. 5133.
[g] Sec. 4094; sec. 5134.
[h] Sec. 4110; sec. 5825.
[i] Sec. 4113; sec. 5828.
[j] Sec. 4140; sec. 5855.
[k] Sec. 4141; sec. 5856.
[l] Sec. 4114; sec. 5829.
[m] Sec. 4115; sec. 5830.
[n] Sec. 4117; sec. 5832.
[o] Sec. 4099; sec. 5139.
[p] Sec. 4096; sec. 5136.

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Surplus waters.—Riparian owners of lands on any stream are given the right to use any surplus or unappropriated waters.[a] Same privilege granted to nonriparian owner.[b]

Loss of rights.—It is provided that failure to comply with the requirements of the statutes deprives the appropriator of his priority against a subsequent appropriator.[c] Lack of diligence in construction forfeits rights.[d]

RIGHT OF WAY.

State lands.—Right of way across state lands is given to irrigation districts for all irrigation work.[e]

Private lands.—A right of way for ditches sufficient for the purpose required[f] is given to all persons, corporations, etc., who may have a right to use water[g] and same may be acquired by condemnation.[h] Such right of way must be the shortest possible route across such land[i] and no landowner will be burdened with more than one ditch, if one will serve the purpose.[j]

Natural streams.—Any person may take water which he has acquired the right to use along any of the streams or lakes of the State, not raising the water above high-water mark.[k]

EMINENT DOMAIN.

Public use.—The use of the waters of the State is deemed a public use[l] and the right of condemnation is given to all persons having a right to use it, for purposes of acquiring rights of way.[m] Procedure is provided in Laws of 1899, page 262.

Riparian rights.—Riparian rights in any natural stream or lake may be condemned[n] but this applies to riparian rights and can not be applied to take water from the person himself using it for irrigation.[o] Procedure is prescribed.[p]

DUTIES OF DITCH OWNERS.

Head-gates, embankments, repairs.—Every ditch owner, owner being the person having charge and control and liable as owner,[q] must erect and keep in good repair a sufficient head-gate at the head of his ditch to control the ordinary flow therein. He must keep embankments[r] and all flumes or other conduits in good repair so as not to injure the premise of others.[s] He is made liable for damages resulting through refusal or neglect to comply with these provisions.[t]

Waste.—Drain ditch shall be provided to return water to stream with as little waste as possible.[u]

Unnecessary diversion.—It is unlawful for any person to run a greater quantity of water through his ditch than is absolutely necessary for irrigation of lands watered and for domestic and stock purposes. A violation of this provision is a misdemeanor punishable by a fine not exceeding $1,000.[v]

DETERMINATION OF RIGHTS.

Basis of determination.—Whenever called into question in any court or before any commissioners (infra) the determination shall be based upon the used volume of water annually flowing in the stream or lake, and in the event of unusually low water, all rights shall be proportionately reduced.[w]

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[a] Sec. 4101; sec. 5816.
[b] Sec. 4106; sec. 5821.
[c] Sec. 4094; sec. 5134.
[d] Sec. 4142; sec. 5857.
[e] Sec. 4203; sec. 5773.
[f] Sec. 4103; sec. 5818.
[g] Sec. 4133; sec. 5848.
[h] Sec. 4109; sec. 5824.
[i] Sec. 4139 and Laws, 1899, p. 261; sec. 5854.
[j] Sec. 4138; sec. 5853.
[k] Sec. 4112; sec. 5827.
[l] Constitution, Article XXI.
[m] Laws, 1899, p. 261.
[n] Sec. 4193; sec. 5763.
[o] Sec. 4156; sec. 5871.
[p] Sec. 4153; sec. 5868.
[q] Sec. 4124; sec. 5839.
[r] Sec. 4119; sec. 5834.
[s] Sec. 4137; sec. 5852.
[t] Sec. 4123; sec. 5838.
[u] Sec. 4119; sec. 5834.
[v] Sec. 4121; sec. 5836.
[w] Sec. 4109; sec. 5824.

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Hearing and adjudication of priorities.—When the owner of any canal in any water district (infra) shall present a written petition to the superior court praying the court to adjudicate priorities between the several canals in the district, the court shall, if deemed practical to proceed, appoint a day to commence to hear and take evidence in such adjudication. All interested parties may offer evidence. The court shall ascertain the date of commencement of the ditch, its original size and capacity, or the time of enlargement and increased capacity, the diligence of construction, and all facts tending to show compliance with the law. He shall determine on the evidence, the priority of appropriation with amounts which each has perfected thereunder, expressed, if possible, in second-feet; if not, by width, depth, and grade of canal.[a]

Certificate.—The clerk shall issue, upon reasonable fee, to each party interested, a certificate, showing dates and amounts of appropriation adjudicated and specifying number of the ditch and of the priority.[a]

Procedure.—Notice of time for adjudication shall be published once a week for four successive weeks; notice containing a copy of said order shall be posted in ten public places [b] in water districts, and proof of such publication and posting shall be made.[c] Service of notice is also provided for.[d]

Decree.—The court in its decree shall number the ditches in the district in the order of priority, and also number appropriations consecutively, beginning with the oldest. Both shall be incorporated in said certificate of the clerk, issued to claimant.[e]

DISTRIBUTION OF WATER.

Water districts.—Each county in the State shall be constituted an irrigation district.[f]

Water commissioners.—A commissioner for each district may be appointed by the county commissioners in each county, at a salary fixed by them, provided that if 12 freeholders, irrigating lands, shall petition therefor the county commissioners must appoint such commissioner.[f]

Such commissioner shall take oath of office and give a bond as may be required by the county commissioners, for the faithful performance of duties,[g] and shall be entitled to compensation at $4 per day, actual employment.[h]

The commissioner may, in emergency cases, employ one or more assistants, who take the same oath and shall receive $3 per day.[i]

Duties of commissioner.—Commissioners must divide the water in natural streams among the ditches taking water therefrom, and in times of scarcity must shut down and fasten head-gates of ditches not entitled to water.[j]

Register of priorities.—A register of priorities must be kept by commissioner when such priorities shall have been determined by commissioner from decrees or other legal source.[k] He must keep record of certificates of courts (supra), with contracts of same.[l]

COURT COMMISSIONERS.

Where insufficient water.—When volume of water in any stream is insufficient, upon application of any party interested, the superior court shall appoint three commissioners to go upon such stream and apportion water, as they may deem equitable. Such apportionment shall be for domestic purposes before any is given for irrigation.[m]

To determine proper diversion.—In the same way the court shall appoint three commissioners to inquire and determine whether or not more water is being diverted than

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[a] Sec. 4159; sec. 5874.
[b] Sec. 4161; sec. 5876.
[c] Sec. 4162; sec. 5877.
[d] Sec. 4163; sec. 5878.
[e] Sec. 4164; sec. 5879.
[f] Laws, 1903, p. 65.
[g] Sec. 4126; sec. 5841.
[h] Sec. 4129; sec. 5844.
[i] Sec. 4130; sec. 5845.
[j] Sec. 4127; sec. 5824.
[k] Sec. 4132; sec. 5847.
[l] Sec. 4160; sec. 5875.
[m] Sec. 4108; sec. 5823.

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is properly used. Their decision is final. They may order the ditch owner to turn back unnecessary water. Failure to comply with the order is punishable as contempt of court.[a]

Rotation of water.—In case of insufficient water in a stream to supply the wants of the entire country through which it passes, the superior court shall appoint three commissioners to apportion in equitable manner a certain amount of water upon alternate days in certain localities with due regard to legal rights of all.[b]

Individual ditches.—When any ditch shall not be entitled to a full supply of water, the amount actually diverted shall be prorated among shareholders and users of water in such ditch.[c]

MISCELLANEOUS PROVISIONS.

Meaning of words "person" and "ditch."—The word "person" wherever used in the statutes means natural person or persons, corporation, or association, and the word "ditch" means dike, flumeway, or irrigation canal.[d]

Interference with appliances.—Every person interfering in any way with head-gates or measuring boxes without authority shall be guilty of a misdemeanor and subject to a fine of not less than $25 or more than $100, or maximum imprisonment of six months, or both.[e]

Injury to ditches.—Any person breaking or injuring the embankment or head-gates of any ditch with malicious intent, or for private gain to injury of persons lawfully using said ditch, shall be guilty of a misdemeanor, punishable by the maximum fine of $500 or maximum imprisonment of six month, or both.[f]

Corporations—deemed common carriers.—Any corporation organized in the State therefor may construct ditches for irrigation, and may condemn rights of way therefor, whether or not said corporation owns lands upon the line of such ditch.[g] Such corporation is deemed a public carrier, and is subject to legislative rules and regulations relating thereto.[h]

Federal Government.—Authority is given to the United States to avail itself of the provisions of the law.[i] Upon authoritative notice to the land commissioner that the Government contemplates the construction of irrigation works, all waters specified will be withdrawn from appropriation under foregoing laws for a period of one year, which withdrawal may be extended three years by certificate from duly authorized agent within the said year that work undertaken appears feasible and further investigation is intended to be made;[j] and upon the letting of contract for construction work the United States may appropriate all unappropriated waters in the manner provided for private persons, the title to beds and shores of state lakes thus utilized passing to the United States upon such appropriation.[k]

CONDITIONS AFFECTING STREAM FLOW.

All water supply is dependent on rainfall. It follows, therefore, that variations in rainfall from year to year are reflected in a general way by variations in stream flow, but local conditions govern the exact relation between rainfall and stream flow to such an extent that only the more prominent modulations are apparent. It is a

[a] Sec. 4111; sec. 5826.
[b] Sec. 4105; sec. 5820.
[c] Sec. 4116; sec. 5831.
[d] Sec. 4118; sec. 5833.
[e] Laws, 1909, p. 271.
[f] Sec. 4157; sec. 5757. See also sec. 7154; sec. 1627; and State *v.* Tiffany et al., December 19, 1906, sheets.
[g] Sec. 4154; sec. 5869.
[h] Sec. 4155; sec. 5870.
[i] Sec. 4165; sec. 5880.
[j] Laws, 1905, p. 180, sec. 3.
[k] Laws, 1905, p. 180, sec. 4.

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common practice among engineers, when stream-flow data are not available—and sometimes even when they are—to make estimates of stream discharge from precipitation data. Such attempts are usually futile in this State. First, because such scattered rainfall stations as are being maintained are located in the valleys or in river canyons in situations which do not afford records representative of large areas; second, because practically no records of precipitation have been kept on the higher portions of the drainage basins, the portions that supply most of the water; third, because local peculiarities of soil, topography, vegetation, etc., render the close determination of the relation between rainfall and stream flow well-nigh impossible, almost every acre of drainage area being a law unto itself, and formulas apparently applicable to one drainage basin being inapplicable to an adjacent one, or even to smaller subdivisions of the same area.

The complexity of the factors that determine the relation between rainfall and river discharge is very evident. The amount of stored water held by the drainage area, either as ground water, in snow banks and glaciers, or in natural lakes and swamps, varies greatly on different areas, and even on different portions of the same area, and it also varies widely with the variations in the amount of precipitation from year to year. Even if the variation in the yearly amount of precipitation were eliminated there would still result great variations in the amount of stored water, depending on the manner and the conditions under which precipitation occurred. Thus snow falling on frozen ground will nearly all appear in the stream when it melts; if the ground is not frozen when the snow falls a large portion of the water may filter into the soil; if gentle rains last for several days less water reaches the stream than if the same amount falls in one day. Hence it is evident that even if the amount of precipitation on a catchment basin were actually determined it would afford a very indifferent indication of the stream discharge.

But, assuming for the moment that precipitation is uniform from year to year, both as to its amount and its distribution as regards time, and that it falls under the same temperature conditions each year, there still remain a number of factors that exert unknown influences on stream discharge. The first and most important of these is the porosity of the soil of which the area is composed. If the soil is practically pure sand, as in the drainage areas of Niobrara and Loup rivers in Nebraska, a very uniform rate of flow will prevail, independent of the monthly variations in rainfall, while the proportionate amount of run-off will be relatively small. If the soil is pumiceous and is underlain with porous lava rocks, as on Deschutes River in Oregon, the same or even greater uniformity of flow will

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result, with even a less proportion of total rainfall appearing as run-off. If the soil is of compact clay or other impervious material, like that of the Crooked or John Day river basins of Oregon, a relatively larger proportion of the total rainfall will appear as stream discharge, but its distribution as regards time will follow more closely the distribution of rainfall, and the stream will be "flashy." These examples illustrate extreme conditions, and of course all intermediate conditions are encountered.

Another important factor is topography. A relatively flat area will discharge a smaller proportion of rainfall, and the flow will tend to uniformity, while the opposite conditions prevail on areas with steep slopes. Soil conditions may be so favorable for ground storage, however, that the effect of topography is entirely obscured.

A third factor is vegetation, both cultivated and natural. Cultivation and cropping tend to render soil porous and thus to increase its power of absorption. This, in turn, tends to increase the uniformity of stream flow. But this factor is comparatively unimportant for the region under discussion, because rarely, if ever, in this country, are the water-producing portions of the drainage area cultivated. It will, however, apply to the plains country of the Middle West and the minor streams that head in the wheat belts of the Northwest. In the scale of importance the vegetation factor is far down the list.

Forests, including brush and undergrowth, constitute the really important class of vegetation that influences stream flow, but the effect of a forest as an equalizer of rainfall is not nearly so great as is popularly believed. The great value of a forest on a drainage area is to prevent soil wash. Still there is no doubt that forests in general have some conserving influence on rainfall, as they aid to some extent infiltration into the soil. Yet this ground water is itself depleted by the forest, for tree growth requires large quantities of water. Thus its beneficial effect is somewhat neutralized by its own requirements. Other things being equal, an open area covered with small bushes, ferns, vines, and tangled underbrush is just as good or even a better conserver of rainfall than a primeval forest, for it offers more resistance to the flow of water along the surface of the ground than is offered by large trees, and permits the formation of snowdrifts, really the great source of surface-water storage.

It is doubtful if the influence of forests as a factor in the run-off will ever be determined with exactness. Their effect is so completely lost in that of a multitude of other factors that it can not be segregated. The citation of a few examples will show that forestation is by no means a guaranty of uniformly flowing streams or of a condition anywhere approaching uniformity, although by no number of

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such examples can it be proved or disproved that the flow of the streams would be less uniform if it were not for the forest.

Deschutes River, in Oregon, is a stream of remarkably uniform flow and about 30 per cent of its drainage area is forested; but its largest tributary, Crooked River, which has about the same proportion of forested area, is perhaps the most "flashy" stream in the State. John Day River, draining the area adjacent to that of Crooked River, is similar in character; it has an enormous flood flow and falls exceedingly low in summer; about 35 per cent of its area, the heaviest water-producing portion, is rather heavily forested. Donner und Blitzen River, in central Oregon, is a very uniform stream with a well-maintained summer flow, but its area does not produce a tree, except here and there a juniper. On the other hand, Silvies River, which exists under the same climatic conditions as Donner und Blitzen River and discharges its waters into the same lake, is anything but uniform in its flow, although its drainage area is heavily forested. Niobrara and Loup rivers, in Nebraska, are very uniform in flow, but there is hardly enough timber on both areas to build a cabin. Nearly all the streams of western Oregon and Washington are subject to enormous floods, and all run comparatively low in summer, yet no streams in the world have more densely forested drainage areas. These examples are not cited to prove that forests have no conserving effect, but rather to show that vegetation is a relatively unimportant factor. The cause of uniform or nonuniform flow can almost invariably be traced to the influence of soil and topography.

Thus it is seen that the determination of the relation between rainfall and stream discharge involves the study of a multitude of very complex conditions. The more data that are gathered and analyzed on this subject the farther away appears to be the solution of the problem. It is far better, therefore, to forego the attempt, except to outline the very broadest tendencies, and instead to place dependence on actual gagings. Even a single year's record of flow is of infinitely more value in determining the behavior of a stream than all the precipitation data that can be compiled. By comparing a single year's record with records for longer time on adjacent or similar areas and using rainfall data for relative yearly variations in a broad way the probable behavior of a stream can be approximately determined.

VARIATION IN STREAM FLOW.

WET AND DRY YEARS.

In determining discharges for the streams under discussion the plan outlined in the preceding section has been followed, except that the record of only the summer flow for one year was available instead

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of a complete year's record. For water-power development alone the summer flow is the more important portion of the yearly discharge. A record of this flow, with an approximate idea of the maximum flood discharge, will usually furnish sufficient data for preliminary analysis of available power and design of structures.

The relative value of 1909 as a water year, in the cycle of wet and dry years, will first be determined. It is an unimportant fact that no rainfall records of value are available for any one of the five drainage areas under consideration. All rain in this region comes from the Pacific Ocean, and any good record of precipitation in the path of the prevailing winds will show relative variations. It is not safe to place too much dependence on the records of a single station; nor can the results at widely separated stations be averaged without showing the more prominent influences of those stations receiving the heavier rainfall. Strictly speaking, the rainfall at any station should be weighted by the area it serves. But this weight is well-nigh impossible to determine, so the more simple expedient has been adopted of expressing the rainfall for each year as a percentage of the mean annual rainfall for that station. The percentages can then be averaged, and the result will show the relative annual variations for the area considered.

In compiling rainfall data for comparison with stream discharge the calendar year for which both rainfall and stream-flow data are published should be discarded and a climatic year substituted. In this paper the climatic year has been used throughout, and has been arbitrarily begun on November 1 and ended on October 31 following. The year in which the ten months appear is used to designate the climatic year. Thus climatic year 1909 began November 1, 1908, and ended October 31, 1909.

By combining the rainfall data at Portland and Fort Vancouver and by supplying a few missing months by estimation from the Astoria records a 57-year record of rainfall has been obtained. A record of thirty years is available at Cascade Locks, one of twenty-five years at Hood River, and one of forty-six years at The Dalles. These are the only stations of value in the vicinity of the region under consideration. They practically indicate the rainfall passing the Columbia River Gap in the Cascade Range, and doubtless afford some indication of precipitation on the Columbia National Forest.

The mean annual rainfall for the climatic year at Portland is 42.3 inches, for Cascade Locks 77.9 inches, for Hood River 35.9 inches, and for The Dalles 16.8 inches. The rainfall for each year for each station has been represented in percentages of the respective means and these percentages have been averaged. The result is called the per cent rainfall for Columbia River Gap. In figure 1 this per cent rainfall is shown in order of magnitude. To illustrate the error of

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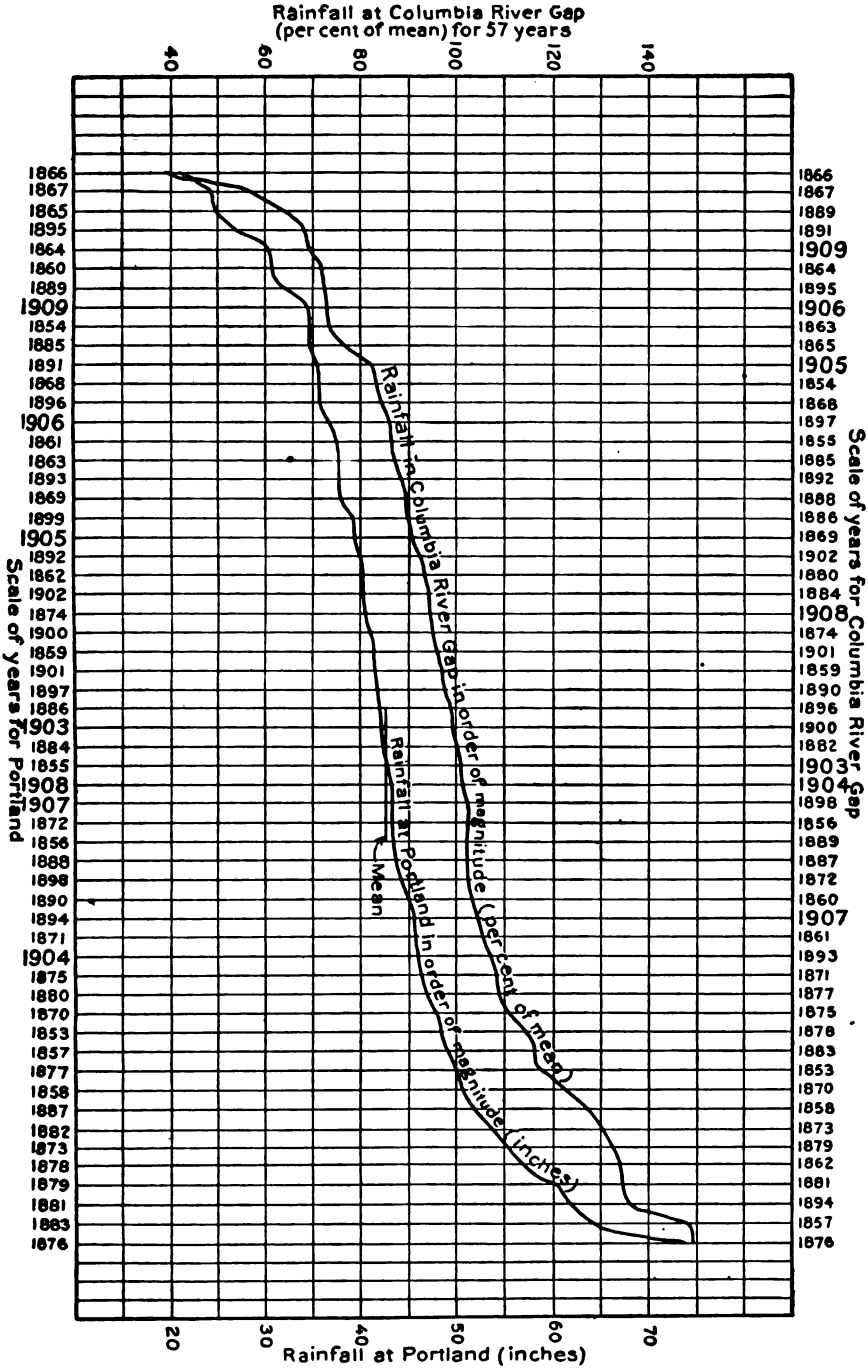

FIGURE 1.—Rainfall curves for Portland and Columbia River Gap, in order of magnitude.

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using the records from a single station in place of the mean for several stations, the same arrangement is shown for the Portland records. In this case, however, the actual rainfall in inches for the climatic years is given.

Rainfall and other climatic phenomena undoubtedly recur in cycles, but all attempts to determine the laws that govern their recurrence have been more or less of a failure. About all that can be said is that wet and dry years usually occur in groups, although a wet year frequently precedes or follows a very dry year. This general tendency can be shown by "smoothing" the rainfall curves. This may be done graphically or algebraically. In the present case the per cent rainfall curve for Columbia River Gap has been "smoothed" by the formula $R' = \frac{1}{10}(a+2b+4c+2d+e)$, where c is the rainfall for any one year, b that for the preceding year, and a for the next preceding; d is for the following, and e the next. R' is the smoothed or cycle value for the year c. This curve is shown in figure 2 for both the per cent rainfall for Columbia River Gap and the Portland record in inches. The actual record, by years, for Portland is also shown by dotted line.

The next question is to determine how closely river discharge may be expected to follow variations in rainfall. Two features will be considered—(1) the annual yield of a drainage area and (2) the minimum flow. Wherever the natural flow of a stream is to be utilized for power development the minimum flow determines the design of the plant; wherever storage is to be employed the annual yield of the drainage area is desired. In this report the water-power tabulations are based on the average minimum flow. In order to properly analyze the variations in this quantity from year to year and the causes therefor, recourse is had to such records of stream flow as are available for streams other than those considered in this report but existing under the same general climatic conditions.

In this general region only one long-time record of stream flow is available, that of Columbia River at The Dalles. By combining the records of gage heights at The Dalles with those at Cascade Locks a continuous record since 1879 has been compiled. A rating curve for the cross section of the river at The Dalles has been developed from gagings made both by the U. S. Engineer Corps and by the United States Geological Survey. The older records of gage heights have been applied to this rating curve and daily discharges determined for the 31 years from 1879 to 1909.

In the same manner the discharge of Willamette River at Albany has been computed from records kept by the United States Weather Bureau for the 17 years from 1893 to 1909.

The annual discharge for both Columbia and Willamette rivers has been reduced to equivalent inches of rainfall over their respec-

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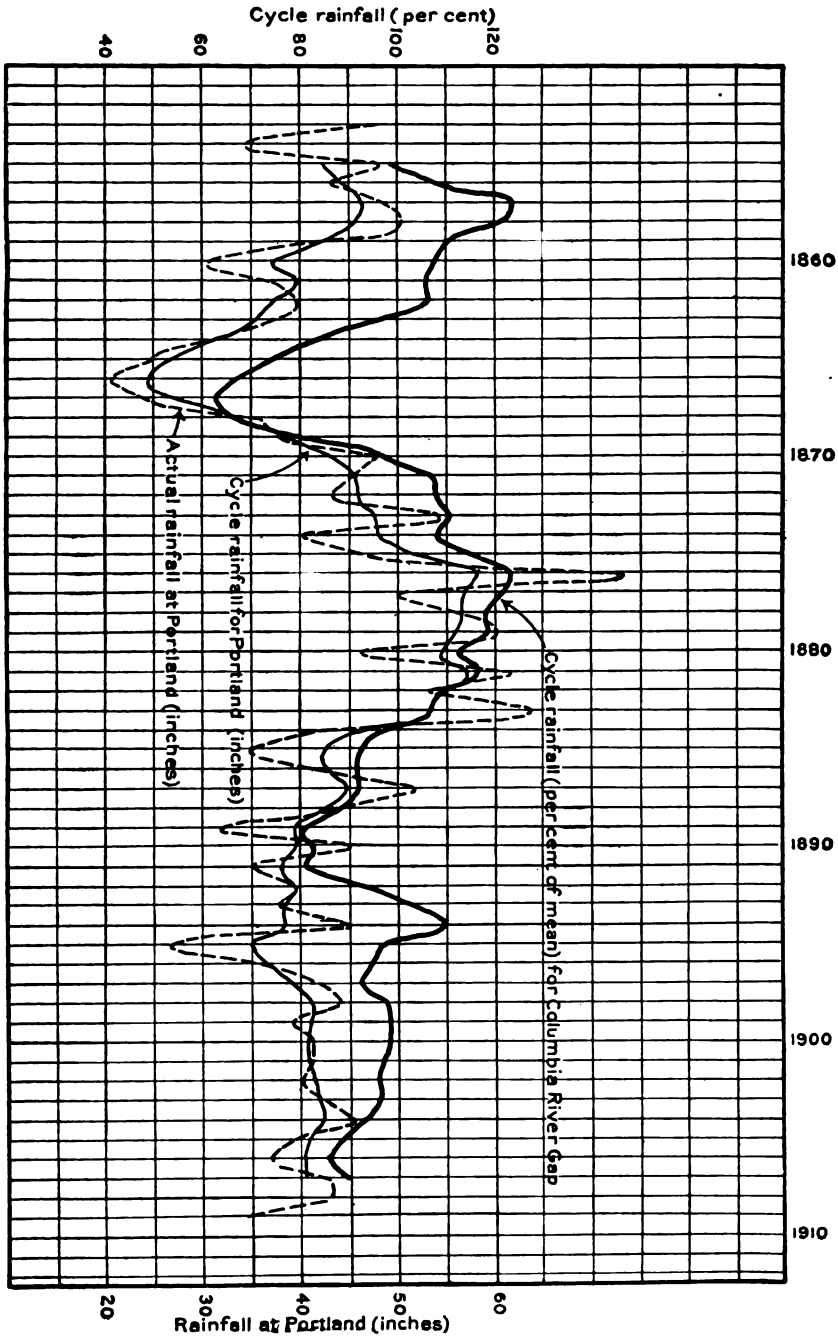

FIGURE 2.—Rainfall cycles, Columbia River Gap and Portland.

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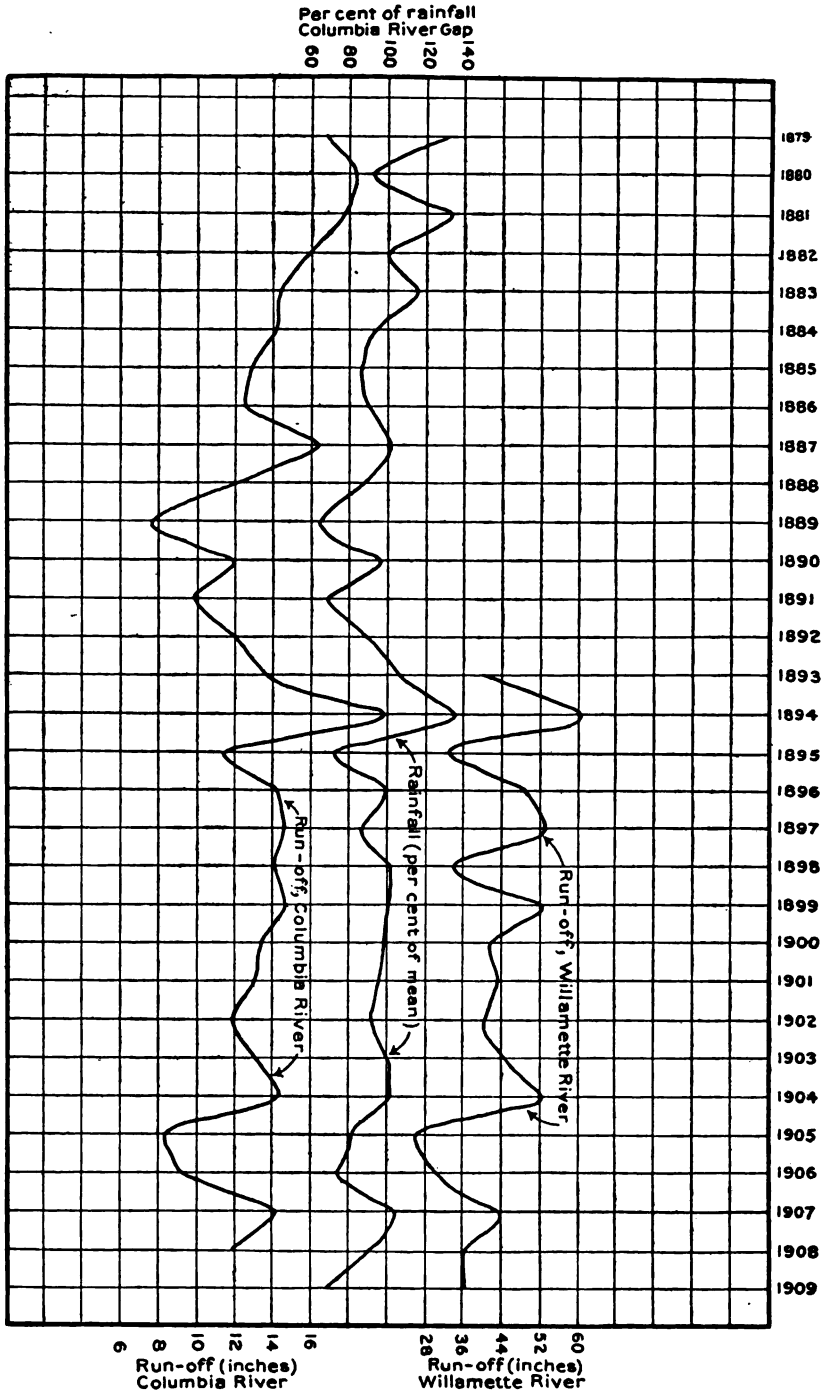

FIGURE 3.—Relation of rainfall to discharge, Columbia and Willamette rivers.

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tive drainage areas. The results are plotted in figure 3. On the same diagram is shown the per cent rainfall for Columbia River Gap, as explained on page 18. The climatic year has been used.

The general parallelism of the rainfall and run-off curves is very striking, particularly in those of Columbia River. Smaller streams would not show this conformity to rainfall variations. No records on small streams of the Northwest are of sufficient length to permit comparison.

ANNUAL YIELD AND MINIMUM FLOW.

Heretofore nearly all stream-flow data in this region have been gathered chiefly for use in connection with irrigation enterprises. The summer flow on these streams is more or less influenced by diversion or artificial storage above the points where the measurements were taken, and the existing stream-flow data are not applicable in such analysis as is presented in this report. However, the data that are available for the Pacific Northwest are given below. The tables give the mean annual discharge for each year and the average discharge for the lowest week, with dates. The average for the lowest week is used instead of the absolute minimum, as this is a more stable quantity for comparison and represents more nearly the quantity that would be used in power-plant design. For Columbia River and Clark Fork, however, the minimum for one day has been used, as sufficient data were not at hand for determining a seven-day average. In addition to these quantities, their value per square mile of drainage area is added, also the variation, in percentage of the yearly value, from the average of all the years given. The climatic year is used throughout—that is, a year beginning November 1 and ending October 31. Where the lowest water occurred in November, this has been credited to that calendar year. Thus, on Umatilla River in 1902 the lowest week ended November 4 and is given in the climatic year 1902, although strictly it falls in the climatic year 1903. If this were not done, we might have two successive minimums from the same low-water period. In general, the minimums selected from low-water periods should be separated by a high-water period. In the analysis of stream-flow data this distinction is not generally made, but it is important when analyzing the minimums for successive years.

The climatic year has distinct advantages in this respect. By adopting it we can deal with a period beginning at a time when conditions of rainfall, stream flow, and temperatures vary little from year to year, and when ground storage and snow and ice storage in mountainous regions are also nearly uniform. The period selected begins just at the end of the low-water period. In other localities different limits would probably have to be selected.

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For a description of the streams selected for this comparison and additional stream-flow data, reference is made to Water-Supply Paper 252 and previous annual publications of the United States Geological Survey on surface-water supplies.

Annual and average minimum discharge of representative streams in the Pacific northwest.

COLUMBIA RIVER AT THE DALLES.

[Drainage area, 237,000 square miles.]

Climatic year.	Mean discharge for the year.			Minimum discharge.			
	Second-feet.	Second-feet per square mile.	Variation from average (per cent).	Month.	Second-feet.	Second-feet per square mile.	Variation from average (per cent).
1879	295,000	1.27	+26	Feb.	66,500	0.278	0
1880	320,000	1.37	+37	Dec.	65,600	.275	− 2
1881	308,000	1.32	+32	...do.	78,700	.329	+18
1882	279,000	1.20	+19	Feb.	67,400	.282	+ 1
1883	252,000	1.08	+ 8	Jan.	65,600	.274	− 2
1884	244,000	1.05	+ 5	Feb.	50,300	.211	−25
1885	223,000	.96	− 4	Jan.	73,400	.307	+10
1886	219,000	.94	− 6	...do.	63,000	.264	− 6
1887	284,000	1.22	+22	Feb.	60,800	.254	− 9
1888	212,000	.91	− 9	Jan.	48,500	.203	−27
1889	133,000	.57	−43	Feb.	58,700	.246	−12
1890	208,000	.89	−11	Jan.	50,300	.211	−25
1891	172,000	.74	−26	Mar.	56,600	.237	−15
1892	211,000	.91	−10	Feb.	64,800	.271	− 4
1893	238,000	1.02	+ 2	...do.	62,000	.260	− 7
1894	338,000	1.45	+45	...do.	86,900	.363	+30
1895	199,000	.86	−15	...do.	78,700	.329	+18
1896	246,000	1.06	+ 5	Jan.	68,400	.286	+ 3
1897	258,000	1.11	+11	Mar.	[a] 83,100	.348	+24
1898	244,000	1.05	+ 5	Nov.	80,600	.337	+21
1899	256,000	1.10	+10	Dec.	57,200	.239	−14
1900	234,000	1.00	0	Oct.	97,000	.406	+45
1901	227,000	.97	− 3	...do.	75,400	.315	+13
1902	208,000	.89	−11	Feb.	57,200	.339	−14
1903	221,000	.95	− 5	Dec.	70,000	.296	+ 6
1904	262,000	1.12	+12	Oct.	73,800	.309	+11
1905	144,000	.62	−38	Feb.	51,800	.217	−22
1906	161,000	.69	−32	Jan.	58,400	.244	−12
1907	240,000	1.03	+ 3	...do.	76,200	.319	+14
1908	206,000	.88	−12	Feb.	59,000	.267	−12
1909	194,000	.83	−17	Jan.	62,000	.259	− 7
Average	233,000	1.00			66,700	.282	

WILLAMETTE RIVER AT ALBANY, OREG.

Climatic year.	Mean discharge for the year.			Mean discharge for the lowest week.			
	Second-feet.	Second-feet per square mile.	Variation from average (per cent).	Week ending—	Second-feet.	Second-feet per square mile.	Variation from average (per cent).
1879	16,400	3.37	+ 9	Sept. 27	1,870	0.385	−36
1892				Nov. 7	2,950	.607	+ 1
1893	14,300	2.94	− 5	Aug. 31	3,000	.623	+ 3
1894	21,700	4.46	+45	Sept. 27	4,000	.823	+37
1895	11,600	2.38	−23	Nov. 6	2,200	.453	−25
1896	17,200	3.54	+15	Oct. 23	2,950	.607	+ 1
1897	18,400	3.78	+23	Sept. 30	3,330	.685	+14
1898	10,300	2.12	−31	Aug. 26	2,760	.568	− 6
1899	18,800	3.87	+25	Oct. 16	3,880	.798	+32
1900	14,800	3.04	− 1	Oct. 1	2,760	.568	− 6
1901	15,600	3.21	+ 4	Aug. 16	2,950	.607	+ 1
1902	14,500	2.98	− 3	Sept. 7	2,950	.607	+ 1
1903	15,900	3.27	+ 6	Oct. 3	3,330	.685	+14
1904	18,900	3.89	+26	Oct. 7	3,140	.646	+ 7
1905	9,250	1.90	−39	Sept. 1	2,400	.494	−18
1906	11,000	2.26	−27	Oct. 5	2,740	.564	− 6
1907	15,600	3.21	+ 4	Oct. 29	2,580	.531	−12
1908	12,900	2.66	−14	Oct. 3	2,810	.578	− 4
1909	12,900	2.66	−14	Oct. 10	2,950	.607	+ 1
Average	15,000	3.09			2,930	.602	

[a] Probably lower in February, but record incomplete.

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Annual and average minimum discharge of representative streams in the Pacific northwest—Continued.

DESCHUTES RIVER NEAR BIGGS (MORO), OREG.

[Drainage area, 9,180 square miles.]

Climatic year.	Mean discharge for the year.			Mean discharge for the lowest week.			
	Second-feet.	Second-feet per square mile.	Variation from average (per cent).	Week ending—	Second-feet.	Second-feet per square mile.	Variation from average (per cent).
1898	6,560	0.715	− 8	Oct. 28	5,200	0.566	−3
1899	7,740	.842	+ 8	Oct. 11	5,680	.607	+6
1900	.....	.....	.....	Sept. 7	5,140	.560	−4
1907	7,970	.868	+12	...do.....	5,700	.621	+6
1908	6,830	.743	− 4	Sept. 30	5,320	.579	−1
1909	6,560	.715	− 8	Aug. 31	5,150	.561	−4
Average	7,130	.776	.....	.....	5,360	.582	.....

JOHN DAY RIVER AT McDONALD, OREG.

[Drainage area, 7,800 square miles.]

1905	1,470	0.188	−20	Sept. 11	93	0.012	−33
1906	1,990	.255	+ 9	...do.....	163	.021	+18
1907	2,950	.378	+60	Sept. 19	210	.027	+51
1908	1,400	.180	−24	Sept. 15	137	.018	− 1
1909	1,360	.174	−25	Sept. 4	90	.012	−35
Average	1,830	.235	.....	.....	139	.018	.....

UMATILLA RIVER AT GIBBON, OREG.

[Drainage area, 353 square miles.]

1896	.....	.....	.....	Sept. 27	80	0.277	+ 8
1897	653	1.84	+25	Sept. 24	75	.212	+ 1
1898	496	1.40	− 5	Aug. 18	74	.210	0
1899	746	2.11	+42	Aug. 11	(a)	.....	.....
1900	.....	.....	.....	July 31	83	.235	+12
1901	722	2.05	+38	Aug. 31	83	.235	+12
1902	509	1.44	− 2	Nov. 4	110	.311	+48
1903	519	1.47	− 1	Aug. 7	78	.221	+ 5
1905	243	.69	−54	...do.....	56	.159	−25
1908	428	1.21	−18	Aug. 22	58	.164	−22
1909	389	1.10	−25	Sept. 2	45	.128	−39
Average	523	1.48	.....	.....	74.2	.209	.....

NACHES RIVER NEAR NILE, WASH.

[Drainage area, 636 square miles.]

1904	.....	.....	.....	Sept. 21	143	0.225	−33
1905	1,020	1.62	− 9	Sept. 12	287	.452	+33
1906	1,060	1.67	− 5	Sept. 4	235	.369	+ 9
1907	1,520	2.29	+36	Oct. 29	203	.319	− 6
1908	1,290	2.03	+15	Oct. 13	228	.359	+ 6
1909	721	1.13	−37	Sept. 20	195	.307	− 9
Average	1,120	1.77	.....	.....	215	.338	.....

a The lowest week for 1899 gives 233 second-feet, but no gagings were made during the year and the record is so doubtful that it is omitted.

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Annual and average minimum discharge of representative streams in the Pacific northwest—Continued.

TIETON RIVER NEAR NACHES, WASH.[a]

[Drainage area, 289 square miles.]

Climatic year.	Mean discharge for the year.			Mean discharge for the lowest week.			
	Second-feet.	Second-feet per square mile.	Variation from average (per cent).	Week ending—	Second-feet.	Second-feet per square mile.	Variation from average (per cent).
1902				Oct. 27	231	0.80	−1
1903	866	3.00	+26	...do.....	360	1.25	+55
1904	743	2.57	+ 8	Nov. 7	232	.803	0
1905	570	1.97	−17	Nov. 17	216	.748	−7
1906	480	1.66	−31	Sept. 17	190	.657	−19
1907	896	3.10	+30	Oct. 10	233	.807	0
1908	702	2.43	+ 2	Oct. 28	238	.825	+ 2
1909	568	1.96	−18	Oct. 31	163	.565	−30
Average	689	2.38			233	.807	

METHOW RIVER AT PATEROS, WASH.

[Drainage area, 1,710 square miles.]

1903				Sept. 10	703	0.411	+48
1904	2,210	1.29	+25	Oct. 9	420	.246	−12
1905	1,890	1.10	+ 7	Sept. 24	528	.308	+11
1906	1,500	.88	−15	Oct. 14	435	.254	− 9
1907	1,860	1.09	+ 5	Nov. 20	453	.265	− 5
1908	1,620	.95	− 8	Oct. 16	388	.227	−18
1909	1,530	.90	−14	Sept. 22	403	.236	−15
Average	1,770	1.04			476	.278	

NOTE.—Lower values for some years are shown in winter, but this is doubtless due to ice conditions.

SPOKANE RIVER AT SPOKANE, WASH.

[Drainage area, 4,000 square miles.]

1896				Nov. 1	1,910	0.478	− 4
1897	9,690	2.42	+23	...do.....	1,970	.493	− 1
1898	10,300	2.57	+32	Oct. 7	2,440	.610	+23
1899	9,400	2.35	+21	Oct. 16	2,360	.589	+19
1900	7,820	1.95	− 1	Sept. 23	2,150	.538	+ 9
1901	8,940	2.23	+14	Oct. 31	2,310	.578	+17
1902	7,640	1.91	− 3	Oct. 28	2,110	.527	+ 6
1903	8,810	2.20	+12	Oct. 5	2,370	.594	+20
1904	8,050	2.02	+ 2	Nov. 16	1,300	.325	−34
1905	3,850	.96	−50	Oct. 1	1,370	.342	−31
1906	5,350	1.34	−33	Oct. 15	1,560	.375	−24
1907	8,370	2.09	+ 6		(b)		
1908	6,070	1.52	−23		(b)		
Average	7,860	1.96			1,980	.495	

[a] On March 7, 1906, the station was moved above Oak Creek; 5 per cent has been added to the annual yield, but no correction has been made to minimum, as Oak Creek is practically dry in summer. Since July, 1907, records are from headworks station and 10 per cent is added to annual yield, but corrections have not been made to minimum on account of small ditches in the canyon.

[b] Low-water period artificially controlled by storage in Cœur d'Alene Lake.

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Annual and average minimum discharge of representative streams in the Pacific northwest—Continued.

CLARK FORK AT NEWPORT, WASH.

[Drainage area, 24,000 square miles.]

Climatic year.	Mean discharge for the year.			Minimum discharge.			
	Second-feet.	Second-feet per square mile.	Variation from average (per cent).	Month.	Second-feet.	Second-feet per square mile.	Variation from average (per cent).
1904	29,500		+13	Feb.	10,400	0.433	+22
1905	15,300		−41	Jan.	5,700	.237	−33
1906	16,800		−35	Mar.	[a] 6,700	.279	−22
1907	34,800		+34	Oct.	[a] 8,420	.351	− 1
1908	30,900		+19	Mar.	[a] 9,150	.381	+ 7
1909	28,600		+10	...do.	[a] 10,800	.450	+27
Average	26,000				8,530	.355	

CEDAR RIVER NEAR RAVENSDALE, WASH.

[Drainage area, 170 square miles.]

Climatic year.	Mean discharge for the year.			Mean discharge for lowest week.			
	Second-feet.	Second-feet per square mile.	Variation from average (per cent).	Week ending—	Second-feet.	Second-feet per square mile.	Variation from average (per cent).
1895				Nov. 9	120	0.706	−37
1896	755	4.44	+ 3	Oct. 21	158	.930	−17
1897	1,160	6.82	+58	Sept. 28	313	1.84	+65
1898	750	4.41	+ 2	Sept. 19	80	.470	−58
1902				Sept. 26	125	.735	−34
1903	780	4.59	+ 6	Aug. 23	140	.823	−26
1904	698	4.10	− 5	Oct. 31	135	.794	−29
1905	557	3.28	−24	[b]			
1906	581	3.44	−21	[b]			
1907	749	4.40	+ 2	[b]			
1908	698	4.10	− 5	[b]			
1909	621	3.66	−16	[b]			
Average	735	4.32			190	1.12	

[a] Probably lower in January or February, but there is no record of daily flow for these months.
[b] Low-water period artificially controlled by storage in Cedar Lake.

It is often said that as the small stream varies so will the large one, but the truth is tersely stated in the homely expression "A river is a river and a creek is a creek." A large river is the final integration of an infinite number of small contributions. Any one of the small tributaries may vary within wide limits with no noticeable effect on the river into which it flows. The Heppner flood of 1903, on Willow Creek, Oregon, destroyed a hundred lives and changed the appearance of the entire valley through which it flowed; but the waters were swallowed by Columbia River with hardly a ripple on its surface.

The variation in the flow of large rivers can be caused only by climatic conditions that affect the entire drainage area. This statement is true also for small creeks, but climatic influences on small areas are called local influences. Hence we expect large rivers to

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respond to general climatic changes and small streams to local influences. We must not necessarily expect small streams to show the lowest water in dry years nor the highest annual yield in wet years. A wet year on the Columbia River basin as a whole may be a dry one on the Spokane basin within it. In Oregon and Washington, and particularly west of the Cascade Range, these exceptions are not so pronounced, however, because the areas are nearer the source of rainfall supply. In other words, the effect of local climate is restricted to much smaller areas here than in States farther east. A corollary of the foregoing proposition is that the minimum flow in a small drainage area may be high in a dry year, owing to local summer showers that do not add anything to the flow of a larger stream.

Unfortunately we do not have discharges data on small drainage areas of sufficient length to test the validity of this statement. Such small streams as have been measured are those used for irrigation, and the summer flow of nearly every one of them is practically all diverted above the point of measurement.

It will be noticed from the foregoing tables that the average minimum varies greatly in the same stream from year to year. On streams where the absolute summer flow is low the variations from year to year will be much greater than on streams where it is relatively high. Thus the minimum for a five-year record on John Day River varies between 90 and 210 second-feet, the range being 133 per cent of the lower figure; on Deschutes River a five-year record shows minimums from 5,150 to 5,700 second-feet, or a variation of only 11 per cent. The same thing is seen to be true of the annual yield. It follows therefore that in a stream characterized by uniformity of flow a record of two or three years' duration will indicate its probable behavior within safe limits, while on nonuniform streams records for ten years or more may be necessary to define its range within the same percentage of error.

It will be seen from the foregoing tables that the minimum does not always vary in the same direction as the annual discharge. In other words, a year of low run-off may have a high summer flow and vice versa. This, however, is more apparent on the smaller streams. The general tendency of the minimums for streams in this list is to follow in the direction of the annual yield.

In order to bring out the relative variations between the annual yield and the minimum rate of flow, Plate I has been prepared. In this plate the solid black bars represent the percentage variation for each year of the mean annual flow, from the average of all the years comprising the record. The climatic year has been used. The open bars represent in the same manner the percentage variation of the mean discharge for the lowest week from the average of all years comprising the record. Those above the zero line, therefore, show

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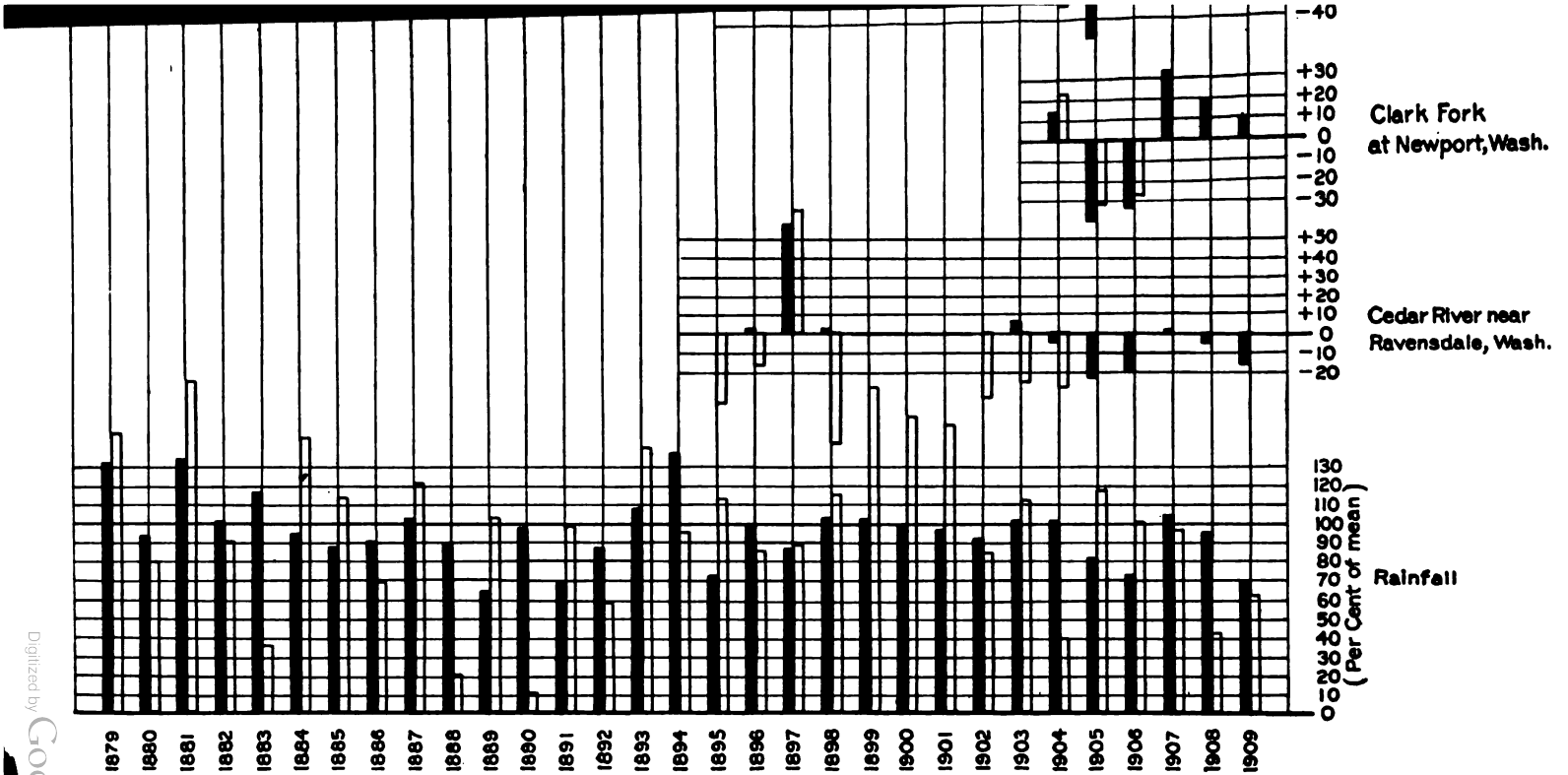

RELATION OF RAINFALL TO DISCHARGE FOR REPRESENTATIVE STREAMS OF THE NORTHWEST.

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that the discharge for that year was above the average or that the percentage variation was in a positive direction. The preceding tables must be consulted for actual values, for only the relative yearly variations are depicted in the diagram.

At the bottom of the diagram are shown the annual variations in rainfall for the stations at Portland, Cascade Locks, Hood River, and The Dalles. The rainfall for each year at each station is first expressed in percentage of the mean annual rainfall for that station. These percentages are then averaged for the several stations. These are shown as solid black bars.

In the same manner the percentage variation of rainfall during the months of August and September for each year at Portland, Cascade Locks, Hood River, The Dalles, Olympia, Ellensburg, and Spokane stations is shown by the open bars. The amount the bars exceed or fall short of 100 per cent indicates the variation from the normal.

The first striking thing about the diagram is the meagerness of available stream-flow data in the Northwest that can be used for a study of this kind. For streams comparable with those of the region under consideration about five years' records constitute the available data. Fortunately these five years include three dry years, one wet year, and one normal year. The year 1905 was a very dry year and was followed by another one in which the precipitation was even less, but the stream discharge did not fall quite so low. The year 1909 also was a very dry year, almost on a parallel with 1905. Segregating the results for these three dry years, we find the following variations:

Variation in percentage of annual discharge and rainfall from the average.

	Length of record (years).	1905.	1906.	1909.
Discharge:				
Columbia River	31	−38	−32	−17
Willamette River	18	−39	−27	−14
Deschutes River	5	.....	.....	− 8
John Day River	5	−20	+ 9	−25
Umatilla River	9	−54	.....	−25
Naches River	5	− 9	− 5	−37
Tieton River	7	−17	−31	−18
Methow River	6	+ 7	−15	−14
Spokane River	12	−50	−33	.....
Clark Fork	6	−41	−35	+10
Cedar River	10	−25	−21	−16
Precipitation	57	−18	−27	−21

With the exception of John Day River in 1906, Methow River in 1905, and Clark Fork in 1909, all these streams show a run-off decidedly below the average, and the precipitation for the Northwest was also very low for these three years. The precipitation in 1909 was 31 per cent below the average for fifty-seven years. The lowest year

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for the period was 1866, when the precipitation was 60 per cent below the normal, followed by 1867 with a precipitation 53 per cent below the normal. (See fig. 1.) The accuracy of these earlier records, however, is in considerable doubt. Discarding them we find two years in which the precipitation during the climatic year was lower than in 1909. These are 1889, in which it was 36 per cent below the normal, and 1891, in which it was 32 per cent below the normal. In 1899 the run-off from the basin of Columbia River was 43 per cent below the 31-year average, and in 1891 it was 26 per cent below. As regards precipitation and run-off from the large rivers of the Northwest, the conditions in 1909 resulted in severe water shortage.

We will now segregate the weekly minimum discharges and the summer rainfall for these years.

Variation in percentage of weekly minimum discharge and summer rainfall from the average.

	Length of record (years).	1905.	1906.	1909.
Discharge:				
Columbia River	31	−22	−12	− 7
Willamette River	19	−18	− 6	+ 1
Deschutes River	6	.....	− 4	− 4
John Day River	5	−33	+18	−35
Umatilla River	10	−25	.....	−39
Naches River	6	+33	+ 9	− 9
Tieton River	8	− 7	−19	−30
Methow River	7	+11	− 9	−15
Spokane River	11	−31	−24	.....
Clark Fork	4	−33	−22	.....
Summer rainfall	31	+17	.....	−37

The general conformity of these data with those in the foregoing table is very satisfactory, but it must be remembered that the drainage areas of these streams are not small and the tendencies indicated for them might not hold good for areas of, say less than 100 square miles. The figures for 1909 are particularly significant. The rainfall during August and September is seen to be 37 per cent below the average for thirty-one years. The average minimum discharge for John Day and Umatilla rivers, draining the Blue Mountains in Oregon, was 35 and 39 per cent, respectively, below the average. For Naches and Tieton rivers, draining the eastern slope of the Cascade Range in Washington, it was respectively 9 and 30 per cent below the average. It should be remembered also that during the five to ten years comprising these records three exceedingly low years are included. It follows therefore that the average for the period of record is low, and as this average is used to determine the relative yearly variations, it must be conceded that the low-water conditions in 1909 are more severe than would at first appear from the above table.

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In applying these deductions to the region under consideration an arbitrary allowance will have to be made for the data obtained during the low-water season of 1909. In the opinion of the writer it would be conservative to increase the average minimum discharges obtained during the summer season of 1909 on the streams surveyed and treated in this report by 20 per cent to obtain a quantity that would represent the average for the past ten years, say, if records had been kept during that period. On this basis, therefore, the tables of water powers have been compiled. That is, the mean discharge for the lowest week in 1909, obtained by current-meter measurement and records of gage height, has been increased 20 per cent, and this quantity is considered as the average minimum discharge for that particular point on the stream.

FLOODS.

It is impossible to determine flood discharge with any degree of accuracy without actual gagings. It is not necessary to measure the discharge at the peak of the flood, but it is necessary to develop a discharge curve for the greater part of the range of the river's stage. This can then be safely extended to cover the highest known stage if the station is at a point where channel conditions are stable.

Many formulas have been advanced for determining the maximum discharge in terms of the drainage area. These formulas, however, are applicable only for the streams used in determining them. When the complex factors that enter into the problem are considered, the futility of devising a general formula, or even formulas for classified conditions, is at once apparent. The maximum rate of flow depends on the maximum rate of rainfall, the temperatures, the quantity of water stored as ice or snow at the time, the condition of the ground at the time of snowfall, the physical nature of the soil, the topography, the vegetation, the times of maximum rainfall and snow melting on tributary portions of the drainage area and the resultant combinations these will produce, and a multitude of other factors, all of which are practically unknown and almost indeterminable.

In the absence of actual data, however, it is frequently necessary to make a tentative estimate of the probable maximum discharge for preliminary study and design. In order that such estimates can be made within reasonable limits, such data as are available on streams draining the Cascade Range are presented in the following table. These have all been determined from actual measurements, as above outlined, and constitute practically all the reliable data known for this region.

It is seen that the discharge per square mile varies between wide limits on different streams. In general, this quantity varies inversely with the drainage area. This results from two causes: First, in

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mountainous regions most of the water is supplied from the altitudes—that is to say, below the mountain slopes and highe hills comparatively little is added to the discharge; second, th of discharge always decreases downstream. The flood wave fore has a sharp crest where it originates, which gradually bre as it advances downstream. Thus the rate of flow is less in the portions of the river than in the higher, while the same total qua of water may pass both places during the entire flood period.

The maximum flood discharge is a very intangible quantity, a is doubtful if the absolute maximum has yet been recorded on a than a few of the streams in the following list. Wherever these a are used, therefore, liberal allowances should be made in the cap ties of spillways.

Flood discharge of streams draining the Cascade Range.

Stream and location.	Drainage area (square miles).	Date of flood.	Maximum dischar	
			Second-feet.	Second- per squ mile.
Streams draining the eastern slope.				
Methow River at Pateros, Wash.	1,710	June 17, 1903	13,100	7.
Wenatchee River at Cashmere, Wash.	1,190	Nov 30, 1909	20,700	17.
Yakima River near Martin, Wash.	56	Nov. 14, 1906	7,200	129
Yakima River at Clealum, Wash.	500	.....do.....	25,600	51.
Yakima River at Umtanum, Wash.	1,540	Nov. 15, 1906	41,000	26.
Yakima River at Yakima, Wash.	3,300	.....do.....	67,000	20.
Clealum River at Roslyn, Wash.	205	.....do.....	18,700	91.
Naches River near Easton, Wash.	63	Nov. 14, 1906	7,000	111
Naches River near Nile, Wash.	263	.....do.....	27,700	74.
Tieton River near Naches, Wash.	289	Nov. 15, 1906	21,000	72.
Deschutes River at Lava, Oreg.	720	Feb. 10, 1907	2,300	3.
Deschutes River at West's ranch, Oreg.	1,240	.....do.....	4,000	3.
Deschutes River at Biggs, Oreg.	9,180	Feb. 6, 1907	30,600	3.
Columbia River at The Dalles, Oreg.	237,000	June 6, 1894	1,390,000	5.
Hood River at Winans, Oreg.	282	Nov. 14, 1906	6,580	23.
Streams draining the western slope.				
Skagit River near Marblemount, Wash.	2,340	Nov. 29, 1909	86,000	36.7
Cascade River near Marblemount, Wash.	222	.....do.....	40,000	160
Cedar River near Ravensdale, Wash.	170	Nov. 15, 1906	10,800	63.5
Willamette River at Albany, Oreg.	4,860	Dec. 8, 1861	220,000	45.3
Clackamas River at Cazadero, Oreg.	685	Nov. 22, 1909	46,800	68.3
South Fork of Santiam River at Waterloo, Oreg.	640	Nov. 15, 1906	36,900	57.6
North Fork of Santiam River at Mehama, Oreg.	740	Feb. 4, 1907	48,900	67.3
McKenzie River near Springfield, Oreg.	960	Nov. 22, 1909	43,500	45.3
Middle Fork of Willamette River at Jasper, Oreg.	1,450	Nov. 23, 1909	123,000	84.8
Molalla River at Molalla, Oreg.	220	Feb. 5, 1907	15,000	68.2
Santiam River at Jefferson, Oreg.	1,890	Nov. 22, 1909	98,000	51.8
South Fork of Umpqua River near Brockway, Oreg.	1,800	Jan. 4, 1907	75,400	41.9
North Fork of Umpqua River at Winchester, Oreg.	1,000	Feb. 4, 1907	58,600	58.6
Umpqua River near Elkton, Oreg.	3,680	Jan. 7, 1907	140,000	38
Rogue River near Tolo, Oreg.	2,020	Nov. 23, 1909	60,000	29.7

KLICKITAT RIVER DRAINAGE BASIN.

DESCRIPTION.

Klickitat River drains the eastern slope of the southern portion of the Cascade Range in Washington. Its position is similar to that of Deschutes River in Oregon, except that the two streams flow in

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opposite directions. Both empty into Columbia River a short distance east of the divide. A map of this drainage basin appears in Plate II.

Klickitat River rises in Goat Mountain, at an elevation of 8,500 feet above the sea, flows generally southward, paralleling the main range of the Cascades, and empties into Columbia River near the town of Lyle. The total length of the main stream is 105 miles. The principal tributaries, named in their order downstream, are, from the west, McCreedy Creek, West Fork, Cunningham Creek, Big Muddy River, Bacon Creek, and Outlet Creek; from the east, Diamond Fork,[a] Piscoe Creek, Surveyors Creek, White Creek, Little Klickitat River, and Swale Creek. The total drainage area is 1,160 square miles, distributed as follows:

	Square miles.
Below the mouth of Diamond Fork	85
Below the mouth of West Fork	254
Below the mouth of Big Muddy River	347
Below the mouth of Little Klickitat River	995
Diamond Fork	43
West Fork	92
Big Muddy River	33
Outlet Creek	87
Little Klickitat River	285

The most prominent feature of the area is Mount Adams, which crowns the summit of the divide at an elevation of 12,307 feet. (See Pl. XII, *A*.) The glaciers on this peak cover 2,300 acres. Those to the east supply the water in Big Muddy River and Little Muddy Creek during the summer months.

The region has been the scene of pronounced volcanic activity and its general topography is in consequence abrupt and rugged. The streams as a rule flow in deep canyons cut into the basalt and lavas. Near the summit of the divide and the spurs that extend from it are a number of grassy meadows bordered by low benches of level or gently rolling land. Many of the meadows are swampy during wet seasons, and lakes occupy the deeper depressions. From the summit of the range eastward the steep slopes of the mountains give way to high, rolling table-lands, into which the streams have cut deeply. The canyon walls are very steep and angular and in places 2,000 feet high. For the most part the rivers occupy the entire floors of the canyons, although on the inside of bends there is usually a flood plain 100 to 500 feet in width.

The soil of the area has resulted from the disintegration of the lavas and basalts. Some of the lavas are very porous, having the

[a] Diamond Fork is locally known as Little Klickitat. It should not be confused with Little Klickitat River, the largest eastern tributary.

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appearance of sponge, and in places considerable scoria and pumice are found. The rocks produce a coarse porous soil that absorbs large quantities of water and readily delivers it to the ground rocks. Thus the ground-storage capacity of the area is relatively high. The result is that the streams have a fairly uniform flow and maintain a good discharge during the summer months. This natural tendency is further augmented by additional waters supplied by the glaciers on Mount Adams and the snowbanks that stand in favored spots well into the summer.

The entire area except the extreme eastern portion is more or less covered with timber. On the west side of the river the growth is heavy, but it gradually thins out toward the eastern boundary of the basin. Only 4 per cent of the total area lies within the Columbia National Forest. In this portion about 80 per cent is heavily timbered and 18 per cent has been burned over. Of the entire area about 75 per cent is timbered, but the stand on over half of this is less than 2,000 feet board measure per acre. In the national forest about 55 per cent of the timber is yellow pine. Red or yellow fir constitutes 20 per cent of the stand, tamarack 10 per cent, white pine 5 per cent, mountain hemlock 5 per cent, and all other species 5 per cent. Over the entire area yellow pine is the predominating species. The sides and bottoms of the canyons are studded with patches of scrub oak in the lower portions, and cottonwoods and alders grow profusely near the water's edge.

Only a small part of the land suitable for agriculture is cultivated. In the vicinity of Glenwood an important amount of hay is cut from the moist table-lands. Irrigation is practiced to some extent on these lands. Hay and the hardier vegetables constitute the principal crops. Wheat is raised in considerable quantities on the high lands in the eastern portion of the drainage area. Irrigation is practiced also on the lower stretches of the river, but the irrigated tracts are small and lie in narrow strips along the river bank in the bottom of the canyon. About 3 miles below Little Klickitat there is a garden and strawberry patch of about 3 acres, which produces abundantly under irrigation.

The only railroad in the area is the Goldendale branch of the Spokane, Portland and Seattle Railway (the "north bank" route). This branch runs from Lyle, on the main line, to Goldendale, near the southeastern border of the area. It follows the river canyon for 17 miles, crossing the river twice in that distance. It leaves the river a short distance above Wright and follows Swale Creek canyon to the uplands. A county road from Goldendale to Glenwood crosses the river near the mouth of Dead Canyon. Between Wright and Parrott's Bridge the canyon is without trails and is well-nigh impassable. From Parrott's Bridge to the source a trail follows the river or the bench lands bordering it. There are also trails along the ridges, but

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A. COLUMNAR BASALT, KLICKITAT CANYON, NEAR GLENWOOD.

B. MAZAMA GLACIER AND HEADWATERS OF HELLROARING CREEK.

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they are almost impassable during the winter months except on snowshoes.

There are a number of mineral springs in the area. Rest Soda Springs is a famous camping resort to which a road has been built down the canyon from the Goldendale-Glenwood road. A ferry was also installed by popular subscription. The soda springs below West Fork furnish an abundance of mineral water fully equal to the water of the famous Shasta Springs in California. Below McCormick Meadows is another soda spring of excellent quality. The water issues from seams in the bed rock.

So far as known the area contains no very large reservoir sites. Many small ones, however, could be developed in the swamps and lakes of the upland benches. The best sites are found on Fish Lake Stream, a tributary of West Fork. Fish Lake, Howard Lake, and Two Lakes could probably be developed to a moderate extent. The grade of Fish Lake Stream is comparatively flat and detailed investigation would probably discover good storage sites. Near the headwaters of Hellroaring Creek there is a favorable site for storage. The waters of this stream are largely supplied from Mazama Glacier (Pl. III, *B*). About a mile below the glacier the stream spreads in two branches through a comparatively flat meadow. The south branch has a good dam site at the east end of the meadow, where a dam 100 feet high could be constructed. The north branch falls over the escarpment, dropping over 200 feet in one-fourth mile. It is likely that considerable storage could be developed at McCormick Meadows on the main stream, 5 miles by trail above the mouth of Diamond Fork. There is little doubt that all these reservoirs would be filled every season.

Discharge data for this river system are very meager. In August, 1900, Sidney Arnold[a] made a brief reconnaissance of Diamond Fork (called Gold Fork in his report, while the main stream above this tributary was called Diamond Fork) in order to determine the feasibility of diverting water from this stream into Atanum Creek basin. The results of Mr. Arnold's investigation show the utter futility of any attempt to divert from the Klickitat basin into the Atanum basin.

The following discharge measurements were made by Mr. Arnold:

August 18, 1900, Diamond Fork near mouth, 48 second-feet.
August 18, 1900, Klickitat River above mouth of Diamond Fork, 11[illegible] second-feet.

In conjunction with the determination of river profiles, discharge measurements of all important tributaries and of the main river at various points were made by the United States Geological Survey during the summer of 1909. Lack of observers made it impossible

[a] Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 4, 1902, pp. 454-455.

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to obtain daily gage heights at the desired points, although gages were installed and favorable sites selected for gaging stations to be established at some future date. One permanent gaging station was established at Wright, where daily gage heights are being recorded. The discharge data at other points in the drainage basin must be estimated from the individual measurements made during the progress of the survey. These are listed as miscellaneous measurements and are arranged in order downstream.

KLICKITAT RIVER ABOVE AND BELOW BIG MUDDY RIVER.

From October, 1904, to June 26, 1908, the Klickitat Irrigation and Power Company made a series of measurements on Big Muddy River and Klickitat River above and below the mouth of the Big Muddy. Through the courtesy of the company the results are presented here as furnished, except that, following the rule of the Geological Survey, discharge data are given only to three significant figures. They were computed to hundredths of a second-foot by the company. No gage heights were recorded.

Discharge measurements on Klickitat River 1,000 feet above the mouth of Big Muddy River, 1905.

[By Klickitat Irrigation and Power Company.]

	Sec. ft.		Sec. ft.
June 19	717	August 11	377
June 29	655	August 18	360
July 8	574	September 2	312
July 15	465	September 15	342
July 22	426		

Discharge measurements of Klickitat River below mouth of Big Muddy River.

[By Klickitat Irrigation and Power Company.]

Date.	Locality.	Discharge.	Date.	Locality.	Discharge.
1905.		*Second-feet.*	1908.		*Second-feet.*
June 5	At Parrot's bridge	1,490	April 3	At Camp Klickitat	1,000
June 12	do	1,590	April 7	do	912
June 19	do	1,210	April 10	do	1,180
June 28	At Robertson's ranch	989	April 14	do	1,770
July 8	do	879	April 18	do	3,050
July 15	do	764	April 21	do	3,270
July 22	do	955	April 24	do	2,700
Aug. 12	do	668	April 28	do	1,940
Aug. 19	do	662	May 1	do	2,270
Sept. 1	do	538	May 5	do	2,180
Sept. 15	do	545	May 8	do	2,510
			May 12	do	1,980
1907.			May 16	do	1,850
July 9	At Camp Klickitat	1,190	May 19	do	1,830
July 16	do	1,080	May 23	do	1,960
July 22	do	950	May 26	do	2,070
July 29	do	884	May 29	do	2,200
Aug. 5	do	824	June 2	do	1,940
Aug. 12	do	695	June 5	do	1,950
Aug. 19	do	753	June 9	do	2,850
			June 12	do	3,010
1908.			June 16	do	2,570
Mar. 2[illegible]	do	1,250	June 19	do	2,050
Mar. 27	do	1,150	June 23	do	1,600
Mar. 30	do	1,060	June 26	do	1,950

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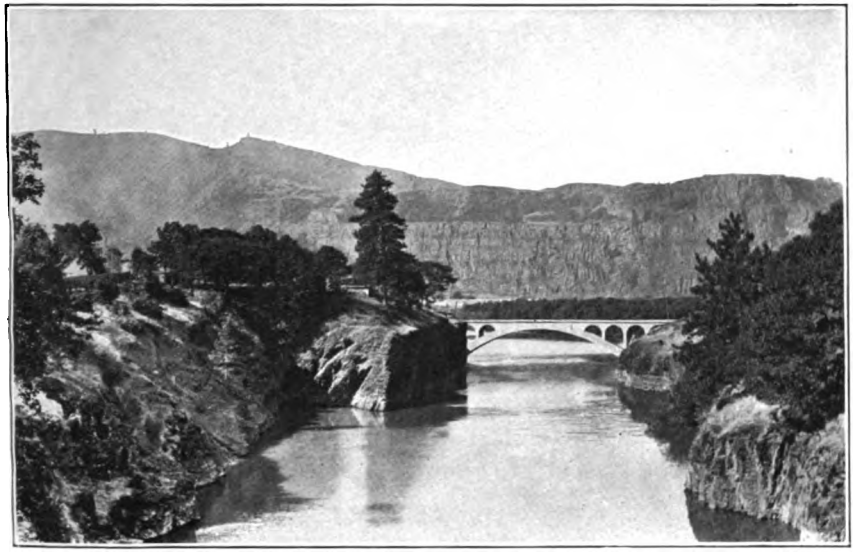
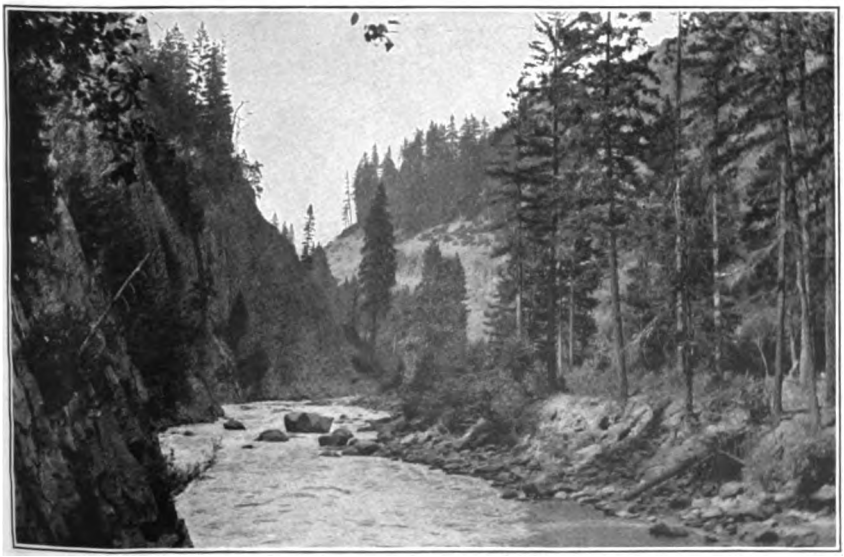


A. KLICKITAT RIVER AT MOUTH.



B. KLICKITAT RIVER AT CAMP KLICKITAT.

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In 1908 and 1909 William R. King, chief engineer of the Klickitat Valley Development Company, made some discharge measurements and had gage readings taken to determine the discharge at the lowest stage during the winter of 1908–9. The results are published here through the courtesy of Mr. King.

The discharge measurements were made with a Lallie meter, the rating table furnished by the manufacturers being used. Later this meter was rated at the United States Geological Survey rating station at Chevy Chase, Md., and it was found that the manufacturer's table gave velocities nearly 17 per cent too low. The original notes of Mr. King have therefore been recomputed, and a revision of his first estimates is given below.

The first gage established by Mr. King was near the Camp Klickitat gaging bridge (Pl. IV, *A*) of the Klickitat Irrigation and Power Company, and the measurements were made from the bridge. The results are therefore comparable with those obtained by that company.

Two measurements were made at this point and gage heights were observed during September and October, 1908. From these the table of discharges has been computed.

Discharge measurements of Klickitat River at Camp Klickitat, 1908.

[By W. R. King.]

Date.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
	Feet.	*Square feet.*	*Ft. per sec.*	*Feet.*	*Second-feet.*
September 13	82	200	3.90	1.30	780
October 23	79	177	3.49	1.08	619

Gage height and estimated discharge on Klickitat River at Camp Klickitat, 1908.

Date.	Gage height.	Estimated discharge.	Date.	Gage height.	Estimated discharge.
	Feet.	*Second-feet.*		*Feet.*	*Second-feet.*
September 13	1.3	790	October 4	1.0	560
September 18	1.0	560	October 7	1.0	560
September 19	1.0	560	October 11	1.0	560
September 21	1.1	635	October 13	1.4	870
September 23	1.0	560	October 17	1.2	710
September 25	1.0	560	October 19	1.3	790
September 28	1.0	560	October 23	1.2	710
October 1	1.1	635	October 25	1.1	635

KLICKITAT RIVER AT HANSON'S CABLE.

The second gage installed by Mr. King was at Hanson's cable, a short distance below the mouth of Outlet Creek. This gage was read during the fall and winter of 1908–9, and probably represents as severe low-water conditions during the winter as will be encountered.

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Discharge measurements of Klickitat River at Hanson's cable.

[By W. R. King.]

Date.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
1908.	*Feet.*	*Square feet.*	*Ft. per sec.*	*Feet.*	*Second-feet.*
October 24	102	237	3.51	2.00	808
October 30	103	273	3.86	2.28	1,050

Gage height and estimated discharge of Klickitat River at Hanson's cable, 1908–9.

Day.	1908.						1909.			
	October.		November.		December.		January.		February.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
1			2.2	970	2.1	890			2.5	1,250
2							1.9	670		
3			2.1	890	2.1	890			2.5	1,250
4							2.1	890		
5			2.1	890	2.0	810			2.4	1,150
6							1.9	740		
7			2.1	890	2.1	890				
8							1.9	740		
9			2.1	890	2.1	890				
10							1.8	670		
11			2.0	810	2.2	970			2.3	1,060
12							1.9	740		
13			2.0	810	2.0	810				
14							1.9	740		
15			2.0	810	1.9	740			2.3	1,060
16							2.0	810		
17			2.1	890	1.9	740			3.2	2,000
18							2.3	1,060		
19			2.4	1,150	1.9	740			3.2	2,000
20							3.1	1,890		
21			2.5	1,250	1.9	740			3.0	1,780
22							2.5	1,250		
23			2.4	1,150	2.0	810			2.8	1,560
24	2.0	810					3.0	1,780		
25			2.3	1,060	2.0	810				
26							2.8	1,560		
27			2.2	970	2.2	970				
28							2.3	1,060		
29			2.2	970	2.1	890				
30	2.3	1,060					3.1	1,890		
31					2.0	810				

KLICKITAT RIVER AT WELS FERRY.

In 1908 and 1909 daily gage heights were recorded at Wels Ferry, about 8 miles below Wright, by Ham, Yearsley & Ryrie, of Spokane. These heights are published through the courtesy of that firm.

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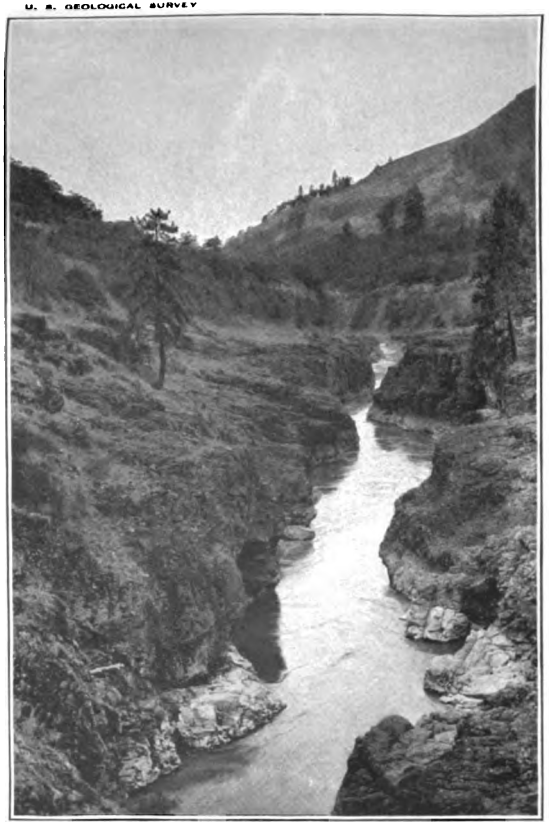
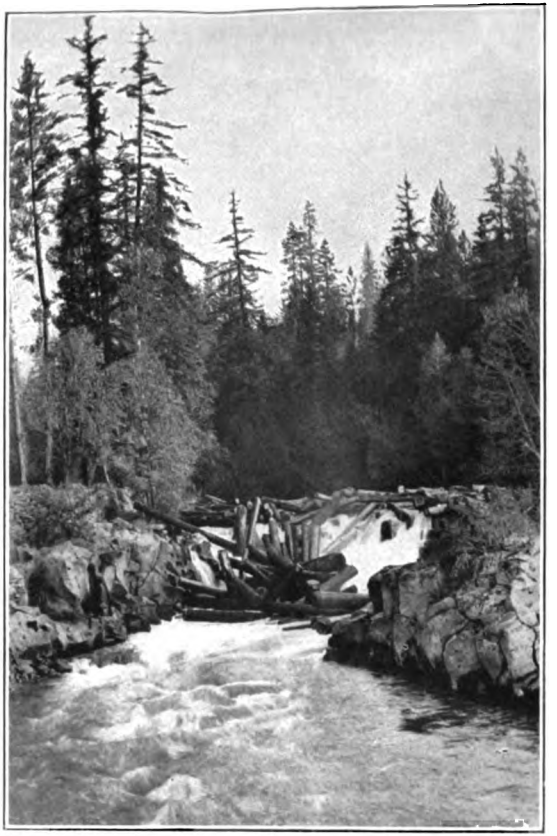


A. BOX CANYON ON KLICKITAT RIVER NEAR MOUTH.



B. LOG DRIVING ON WHITE SALMON RIVER NEAR HUSUM GAGING STATION.

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Daily gage height, in feet, of Klickitat River at Wels Ferry, near Lyle, Wash., 1908–9.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1908.											
1	0.7	−0.2	0.4	0.75	.....	1.1	0.85	.....	.....	.....	.....
2	.55	− .15	.45	.7	.....	1.0	.85	.....	.....	.....	.....
3	.45	− .1	.4	.7	1.2	.95	.9	.....	.....	.....	.....
4	.4	.....	.35	.75	1.25	.95	.8	.....	.....	.....	.....
5	.35	.1	.35	.75	1.25	.95	.7	.....	.....	.....	.....
6	.3	.4	.3	.7	1.3	1.0	.65	.....	.....	.....	.....
7	.3	.2	.3	.65	1.3	1.15	.7	.....	.....	.....	.....
8	.35	.1	.25	.6	1.25	1.35	.7	.....	.....	.....	−0.4
9	.7	.3	.25	.65	1.25	1.45	.7	.....	.....	.....	.....
10	.65	.5	.20	.7	1.2	1.6	.75	.....	.....	.....	.....
11	.55	.45	.20	.75	1.15	1.65	.7	.....	.....	−0.35	.....
12	.5	.4	.35	.9	1.1	1.6	.7	.....	.....	.....	.....
13	.5	.3	.45	1.05	1.05	1.5	.75	.....	.....	.....	.....
14	.45	.2	.35	1.15	1.0	1.35	.7	.....	.....	.....	.....
15	.35	.15	1.9	1.1	1.1	1.3	.65	.....	.....	.....	.....
16	.3	.1	2.7	1.15	1.25	1.25	.6	.....	.....	.....	.....
17	.5	.15	2.75	1.4	1.25	1.15	.55	.....	.....	.....	.....
18	.45	.2	2.45	1.85	1.2	1.05	.45	.....	.....	.....	.....
19	.55	.25	1.9	2.15	1.2	1.0	.45	.....	.....	.....	.....
20	.65	.3	1.55	2.1	1.15	.9	.45	.....	.....	.....	.....
21	.6	.25	1.35	1.9	1.1	.85	.45	.....	.....	.....	.....
22	.4	.2	1.35	1.65	1.05	.75	.4	.....	.....	.....	.....
23	.3	.2	1.3	1.6	1.0	.6	.4	.....	.....	.....	.....
24	.25	.3	1.25	1.55	1.15	.65	.4	.....	.....	.....	.....
25	.25	.3	1.25	1.45	1.2	.75	.35	.....	.....	− .4	.....
26	.2	.35	1.2	.....	1.25	.85	.....	.....	.....	.....	.....
27	.15	.4	1.15	.....	1.25	.85	.....	.....	.....	.....	.....
28	.1	.45	1.1	.....	1.25	.8	.....	.....	.....	.....	−0.4
29	.05	.35	1.0	.....	1.25	.85	.....	.....	.....	.....	.....
30	− .1	.....	.9	.....	1.25	.85	.....	.....	.....	.....	.....
31	− .15	.....	.85	.....	1.2	.....	.....	.....	.....	.....	.....
1909.											
1	.....	.4	1.25	1.05	.95	1.6	.4	0.05	−0.15	− .25	− .15
2	.....	.65	1.3	1.0	1.0	1.85	.4	.05	− .15	− .25	.15
3	.....	.8	1.2	.95	1.15	1.8	.4	.1	− .15	.....	.75
4	.....	.65	1.05	.9	1.35	1.7	.4	.1	−1.1	.....	1.15
5	.....	.75	.95	.85	1.45	1.65	.4	.1	− .1	.....	.65
6	.....	.65	.85	.75	1.35	1.4	.5	.15	− .1	.....	.5
7	.....	.55	.75	.7	1.25	1.3	.45	.15	− .15	.....	.45
8	.....	.45	.7	.7	1.15	1.2	.4	.1	− .15	.....	.35
9	.....	.4	.65	.75	1.10	1.15	.4	.1	− .15	.....	.25
10	.....	.35	.65	.85	1.05	1.1	.35	.05	− .2	− .3	.1
11	.....	.25	.6	.9	1.0	1.1	.35	.05	− .2	− .3	.05
12	.....	.3	.65	1.0	.9	1.05	.35	0	− .2	− .3	0
13	.....	.4	.7	1.05	.9	1.1	.3	− .05	− .2	− .3	0
14	.....	.45	.75	1.1	.95	1.05	.3	− .05	− .2	− .3	− .15
15	.....	.55	.85	1.05	.95	1.0	.25	− .1	− .2	− .3	− .3
16	.....	.95	.9	1.0	.95	1.0	.25	− .1	− .2	− .3	− .3
17	.....	1.85	.95	1.05	1.0	1.05	.2	− .15	− .2	− .3	− .25
18	.....	2.25	1.05	1.05	1.0	1.1	.2	− .15	− .2	− .3	− .1
19	.....	1.95	.95	1.0	1.05	1.05	.2	− .2	− .25	− .3	1.45
20	.....	1.65	.9	1.05	1.1	.95	.15	− .1	− .25	− .3	1.75
21	.....	1.35	.85	.95	1.15	.9	.2	− .05	− .25	− .3	.....
22	.....	1.15	.8	.85	1.1	.8	.25	.....	− .25	− .3	.....
23	.....	1.05	.7	.85	1.05	.75	.2	.....	− .3	− .3	.....
24	.95	1.35	.75	.9	1.1	.7	.2	.....	− .3	− .3	.....
25	.85	1.45	.8	1.0	1.15	.65	.2	.....	− .3	− .3	.....
26	.7	1.45	.8	1.05	1.35	.6	.2	.....	− .25	− .3	.....
27	.65	1.1	.85	1.15	1.95	.55	.15	.....	− .25	− .3	.....
28	.5	1.05	.95	1.05	1.55	.5	.15	.....	− .25	− .3	.....
29	.35	.....	1.05	1.0	1.4	.45	.1	− .2	− .2	− .3	.....
30	.3	.....	1.15	.9	1.45	.45	.1	− .2	− .2	− .3	.....
31	.3	.....	1.15	.....	1.55	.....	.05	− .2	.....	− .25	.....

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KLICKITAT RIVER AT WRIGHT.

This station was established July 3, 1909. The gage is on the right bank just back of the post-office, 14 miles above the mouth of the river. At present discharge measurements are made from the railroad bridge, three-fourths of a mile upstream from the gage. The reference point at the bridge is the top of a railroad spike in the downstream end of the right abutment. The water surface at the time of gaging is referred to this reference point as well as to the gage three-fourths of a mile downstream.

The bench mark at the gage is a 20-penny spike in the stream face of a 12-inch alder on the right bank 8 feet back and 3 feet downstream from the gage. Its elevation is 8.15 feet above the zero of the gage. The banks of the river at this point will not overflow and the channel conditions are favorable for good results.

Only two measurements have thus far been made. The one in 1907 has been referred to the gage by comparative readings on it and the reference point at the bridge.

Discharge measurements of Klickitat River at Wright, Wash.

[By H. D. McGlashan.]

Date.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
	Feet.	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Sec.-ft.*
Sept. 6, 1907	86	204	5.19	2.15	1,060
July 14, 1909	93	266	5.83	2.58	1,550

Daily gage height, in feet, of Klickitat River at Wright, Wash., for 1909.

[Mrs. M. A. Young, observer.]

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.34	2.05	1.92	2.40	4.9	16	2.6	2.15	2.00	1.90	1.95	3.45
2	.....	2.29	2.05	1.90	3.00	4.5	17	2.5	2.18	1.98	1.90	2.10	3.32
3	2.9	2.30	2.02	1.90	3.82	4.1	18	2.48	2.18	1.92	1.88	2.88	3.20
4	2.85	2.28	2.08	1.90	3.45	3.8	19	2.45	2.22	1.92	1.92	4.11	3.14
5	2.85	2.28	2.05	1.98	2.95	3.67	20	2.45	2.22	1.92	1.95	4.12	3.06
6	2.82	2.22	2.05	1.92	2.45	3.55	21	2.45	2.18	2.02	1.95	3.42	2.75
7	2.8	2.21	2.02	1.90	1.98	3.4	22	2.5	2.08	1.98	1.92	(a)	2.75
8	2.8	2.21	2.05	1.90	1.98	3.4	23	2.5	2.10	1.92	1.90	(a)	2.70
9	2.8	2.21	2.08	1.95	2.48	3.3	24	2.5	2.08	1.92	1.90	(a)	2.72
10	2.75	2.22	2.00	1.98	2.40	3.2	25	2.42	2.08	2.00	1.90	5.40	2.80
11	2.7	2.18	1.95	1.98	2.32	3.18	26	2.38	2.20	1.95	1.90	4.70	2.75
12	2.68	2.18	1.98	1.95	2.22	3.60	27	2.36	2.12	2.30	1.88	4.25	2.72
13	2.61	2.18	2.00	1.92	2.20	4.08	28	2.38	2.05	2.00	1.90	4.40	2.65
14	2.6	2.18	2.00	1.95	2.12	3.72	29	2.38	2.05	2.00	1.90	4.85	2.58
15	2.6	2.12	2.00	1.95	1.92	3.52	30	2.39	2.05	1.95	1.88	5.50	2.62
							31	2.32	2.05	.....	1.92	.....	2.69

a Water over the gage.

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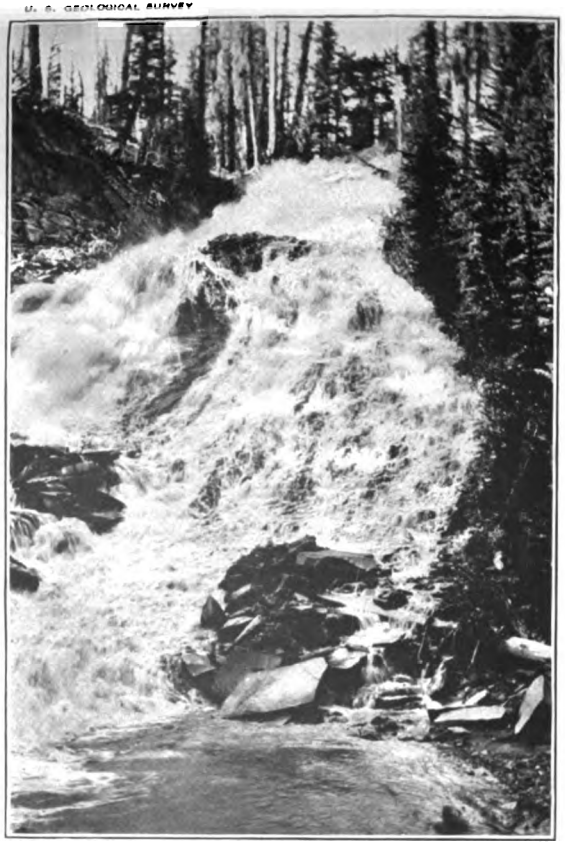

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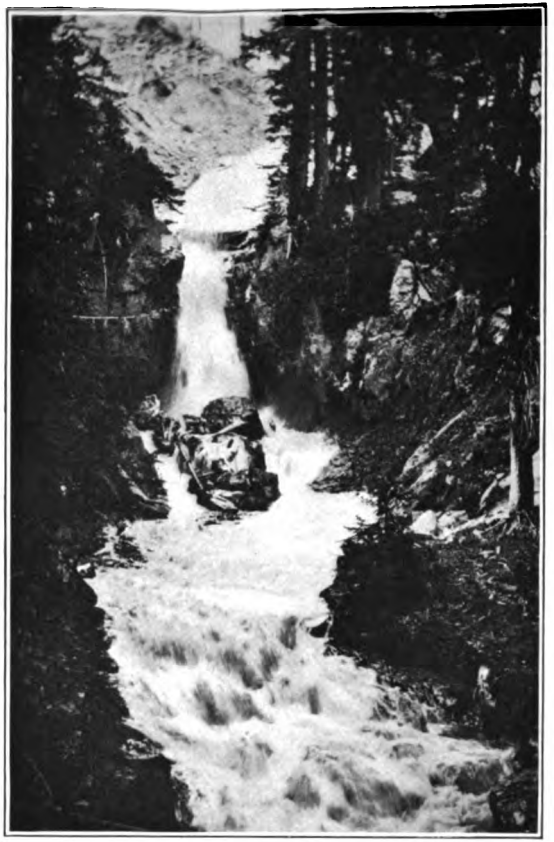

B.

FALLS ON HELLROARING CREEK NEAR HEAD.

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Daily discharge, in second-feet, of Klickitat River at Wright, Wash., for 1909.

Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.
1.....	1,250	950	828	11.....	1,080	855	882	21.....	1,080	920	855
2.....	1,200	950	810	12.....	1,080	882	855	22.....	980	882	828
3.....	1,210	920	810	13.....	1,080	900	828	23.....	1,000	828	810
4.....	1,190	980	810	14.....	1,080	900	855	24.....	980	828	810
5.....	1,190	950	882	15.....	1,020	900	855	25.....	980	900	810
6.....	1,120	950	828	16.....	1,050	900	810	26.....	1,100	855	810
7.....	1,110	920	810	17.....	1,080	882	810	27.....	1,020	900	794
8.....	1,110	950	810	18.....	1,080	828	794	28.....	950	900	810
9.....	1,110	980	855	19.....	1,120	828	828	29.....	950	900	810
10.....	1,120	900	882	20.....	1,120	828	855	30.....	950	855	794
								31.....	950	.....	828

Monthly discharge of Klickitat River at Wright, Wash., for 1909.

[Drainage area, 1,090 square miles.]

Month.	Discharge in second-feet.				Accuracy.
	Maximum.	Minimum.	Mean.	Mean per square mile.	
August	1,250	950	1,080	0.99	B.
September	980	828	897	.82	B.
October	882	794	828	.76	B.
The period	1,250	794	935	.86	

BIG MUDDY RIVER.

The following estimates of the discharge of Big Muddy River are made by taking the differences of discharges measured during 1905 above and below its mouth on the same or succeeding days. Some spring water is contributed above Robertson's ranch and Camp Klickitat. For estimates made at Parrot's bridge Dairy Creek should be included. The discharge of Dairy Creek August 6, 1909, was 4 second-feet.

Discharge measurements of Big Muddy River above mouth of Cougar Creek, 1908.

[By Klickitat Irrigation and Power Company.]

	Sec.-ft.		Sec.-ft.
May 5	168	June 2	193
May 8	172	June 5	194
May 13	159	June 9	311
May 16	152	June 12	304
May 19	158	June 16	327
May 23	165	June 19	258
May 26	180	June 23	207
May 29	191	June 26	251

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Estimates of discharge of Big Muddy River, 1905.

	Sec.-ft.		Sec.-ft.
June 19	490	August 11, 12	290
June 28, 29	343	August 18, 19	302
July 8	305	September 1, 2	226
July 15	300	September 15	202
July 22	528		

MISCELLANEOUS MEASUREMENTS.

The following miscellaneous discharge measurements were made in the Klickitat basin in 1909:

Miscellaneous measurements in Klickitat River basin, 1909.

[By H. D. McGlashan.]

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
			Feet.	*Sq. ft.*	*Ft. per sec.*	*Sec.-ft.*
August 25	Diamond Fork [a]	Mouth	22	18	1.61	29
Do	Klickitat River [b]	Below Diamond Fork	37	45	2.00	90
Do	Piscoe Creek	Mouth (estimated)				6
August 21	McCreedy Creek	do				20
August 19	Pearl Creek	do				2
August 20	Klickitat River [c]	Above Pearl Creek	61	61	1.92	117
August 19	Chaparral Creek	Mouth (estimated)				1
Do	Corral Creek	do				1
August 18	Klickitat River [d]	Above West Fork	60	106	1.45	154
August 31	do. [e]	do	54	91	1.57	143
August 18	Swamp Creek	Mouth (estimated)				6
Do	West Fork [f]	1½ miles above mouth	57	91	3.36	306
August 31	do. [g]	1 mile above mouth	65	96	2.75	264
August 28	Fish Lake Stream [h]	Mouth	40	66	1.61	106
Do	Little Muddy Creek	¼ mile above mouth	31	29	4.03	117
Do	Clearwater Creek [i]	Mouth	22	41	1.15	47
August 16	Soda Springs Creek	Soda Springs (estimated).				1
August 31	Klickitat River [j]	Soda Ford	104	148	2.24	331
August 16	Surveyors Creek	1 mile above mouth	12	8.9	.94	8.4
August 13	Cunningham Creek	Mouth (estimated)				12
September 3	Klickitat River [k]	Above Big Muddy River	68	112	3.5	397
September 4	Hellroaring Creek [l]	2 miles above mouth	21	32	2.87	92
August 9	Cougar Creek [m]	Mouth (estimated)				3
Do	Klickitat River [n]	¾ mile below Big Muddy River.	84	198	3.7	732
September 3	do. [o]	do	83	191	3.86	738
August 6	Dairy Creek	Mouth (estimated)				4
August 4	Bacon Creek	do				8
July 31	Outlet Creek	Bodie ranch	10	6.5	.92	5.7
July 14	Klickitat River [p]	Wright	93	2.66	5.83	1,550

[a] Water surface 2.97 feet below 10-penny nail in 24-inch cottonwood on left bank, 150 feet upstream from United States Geological Survey bench mark.

[b] Water surface 3.10 feet below 10-penny nail in 5-inch alder on right bank, 8 feet below two 18-inch cotton woods, 300 feet below mouth of Diamond Fork.

[c] Made 900 feet above mouth of Pearl Creek, opposite water-right notice of Klickitat Irrigation and Power Company.

[d] Water surface 2.76 feet below 10-penny nail in upstream side of foot log near right bank, 600 feet above mouth of West Fork.

[e] Water surface 2.86 feet below reference point described for gaging of August 18.

[f] Water surface 3.10 feet below 10-penny nail in upstream face of 18-inch cedar on right bank, near trail crossing.

[g] Gaged one-half mile below point of measurement of August 18; water surface 3.14 feet below reference point described for that gaging.

[h] Fish Lake Stream and Little Muddy Creek unite to form West Fork. Gaging made below mouth of Clearwater Creek.

[i] Tributary of Little Muddy River; water clear; high-water marks 1.5 feet above this stage.

[j] Gage height 2.20 feet on gage established on right bank, 25 feet above trail crossing 1 mile below Soda Ford, 4 miles below West Fork; excellent site for gaging station.

[k] Water surface 4.33 feet below crosscut on stream face of 12-inch alder on right bank near perpendicular basalt cliff; results excellent.

[l] Tributary of Big Muddy river, gaged at sheep bridge 2 miles above mouth; extreme high water is about 1.0 foot above present stage; water is color of dark chocolate.

[m] Tributary of Big Muddy River.

[n] Gaged from bridge at Camp Klickitat; an old gage 50 feet upstream from bridge on right bank read [illegible] channel conditions not favorable for good results.

[o] [illegible]ed from bridge at Camp Klickitat; gage read 0.47.

[p] [illegible]ed from railroad bridge; gage height 2.58 at Wright.

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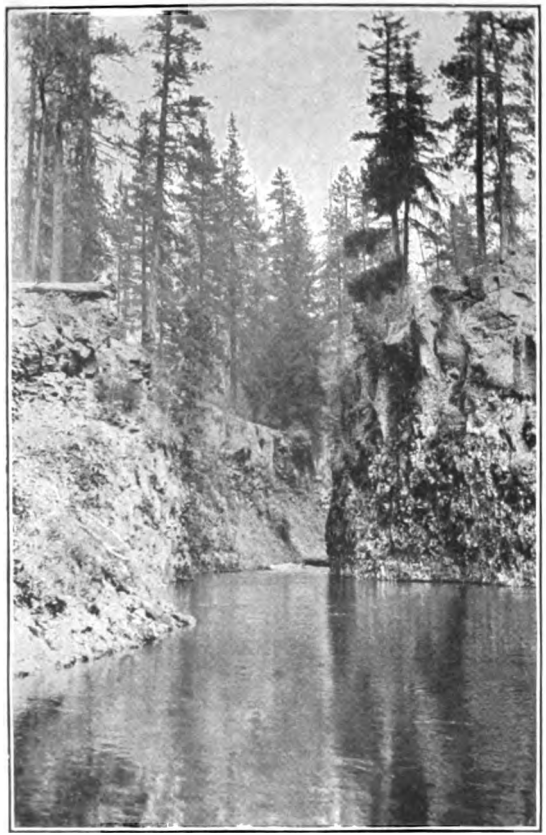
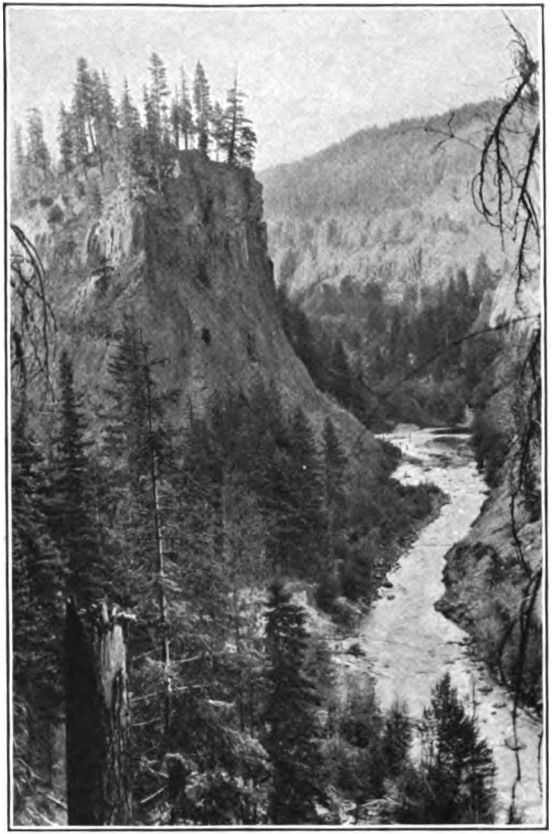


A. DAM SITE ON KLICKITAT RIVER ABOVE WEST FORK.



B. MUDDY POINT, AT MOUTH OF BIG MUDDY RIVER.

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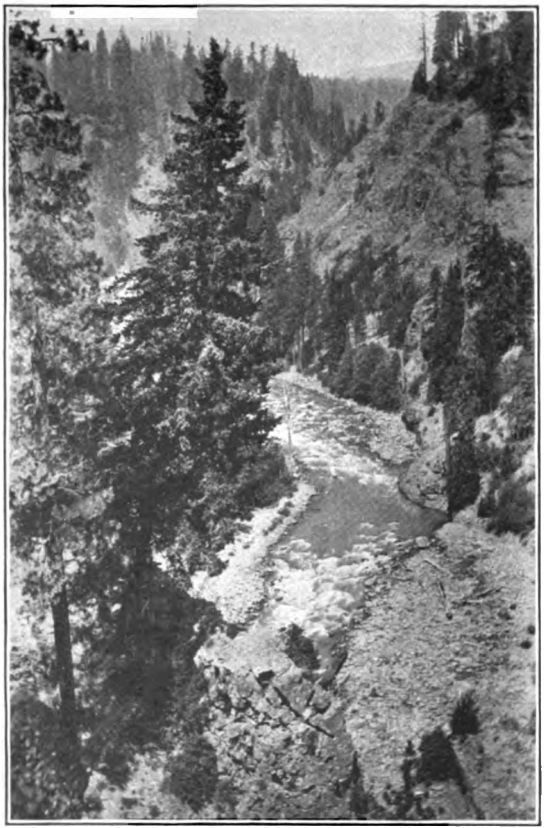
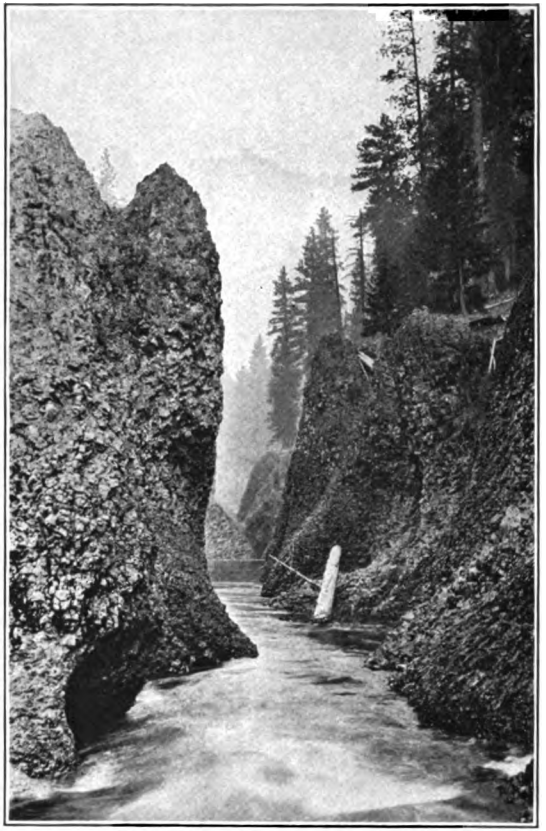


A. KLICKITAT RIVER NEAR GLENWOOD.



B. KLICKITAT RIVER NEAR CASTILE FORD.

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AVERAGE MINIMUM DISCHARGE.

From the foregoing data the following table has been compiled. The average minimum is taken as the mean discharge for the lowest week and is arbitrarily increased 20 per cent, as explained on page 31. Where only miscellaneous measurements are available the average minimum has been estimated by considering the relation of the time at which these measurements were made to that of the lowest week. Allowance has also been made for intervening accretions to the flow as indicated by springs or tributaries measured or estimated.

Average minimum discharge for Klickitat River drainage basin.

Locality.	Drainage area.		Date.	Measured discharge.	Adjusted to average minimum.
	Square miles.	Per cent of total.			
				Sec.-ft.	*Sec.-ft.*
Klickitat River:					
Below Diamond Fork	85	7	August 25, 1909 [a]	90	80
Below McCreedy Creek	129	11	.....	.....	105
At Castile Ford	150	13	.....	.....	120
Below West Fork	254	22	.....	.....	370
Below Big Muddy River	347	30	October 11, 1908 [b]	560	590
Below Outlet Creek	528	46	January 12, 1909 [b]	720	790
At Alvord's bridge, sec. 12, T. 5, R. 13	663	57	.....	.....	800
Below Little Klickitat River	995	86	.....	.....	900
At Wright gaging station	1,090	94	October 30, 1909 [b]	807	970
At head of box canyon	1,140	99	.....	.....	1,000
Fish Lake Stream and West Fork:					
At head of survey	38	.....	August 28, 1909 [a]	106	120
Below Little Muddy Creek	83	.....	Winter	264	190
Big Muddy River below Hellroaring Creek	23	.....	.....do.....	.....	100

[a] Date of miscellaneous measurement used as a guide.
[b] Date of ending of week for which the mean discharge was the lowest.

These discharges are compiled for the purpose of estimating water power; therefore the use of the water for that purpose must be considered. On the glacial streams (Big Muddy River and its tributaries and Little Muddy Creek) the lowest period occurs during the cold weather in the winter. Their availability for power development is therefore governed by the winter minimums. On the main stream the summer minimums govern. During the summer low-water period the glacial streams are comparatively high; during the winter low-water period the nonglacial streams are comparatively high. Hence for a power plant on Big Muddy River the estimated winter minimum of 100 second-feet is used; but for a plant on the main Klickitat below Big Muddy River an estimate of 200 second-feet is used for that part contributed by the Big Muddy during this minimum period on the main stream. Similarly, for Fish Lake Stream (nonglacial) the estimate is 120 second-feet, while for West Fork below the mouth of the Little Muddy 190 second-feet is used for the winter flow on account of portions contributed by Little Muddy Creek. But for the main stream below West Fork 250 second-feet is used as the probable contribution of West Fork,

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because during the summer season Little Muddy Creek is comparatively high.

WATER POWERS.

On account of the fairly steep grade, well-maintained flow, and rocky canyons through which Klickitat River and its tributaries flow, the system offers some exceptionally favorable opportunities for power development. At present, however, there are no such developments in the drainage area, although several water filings have been made for power and irrigation.

The filings of the Klickitat Irrigation and Power Company contemplate the diversion of the waters of Klickitat River for the irrigation of lands in the Horseheaven district. The lands to be irrigated lie on the high table-land between Columbia and Yakima rivers south of the city of Prosser. The project involves the construction of a canal about 150 miles long and the development of such storage facilities as the area to be traversed affords. The water is to be diverted from Fish Lake Stream and the main Klickitat above the mouth of West Fork.

The Klickitat Valley Development Company is engaged in the construction of a project for the irrigation of the table-lands in the vicinity of Glenwood. Water diverted below the mouth of Big Muddy River can be carried upon the lands by gravity flow, affording some good incidental opportunities for power development.

Ham, Yearsley & Ryrie, of Spokane, Wash., have made filings on the lower Klickitat for power development. This project contemplates the laying of large pipe lines along the sides of the canyon and the erection of a power house near the mouth of the river.

West Fork and Big Muddy River offer some favorable opportunities for high-head developments. The streams flowing directly from Mount Adams, are almost literally "on end," and there are numerous falls which could readily be utilized for power development. Below the mouth of Hellroaring Creek Big Muddy River enters a box canyon, in places not over 6 feet wide, cut into the basalt. The total fall in the last 3½ miles is 968 feet. Above the mouth of Hellroaring Creek this stream falls 1,300 feet in 4 miles over large bowlders that fill the river bed. The bed of Hellroaring Creek is similarly strewn with bowlders, and the waters fall nearly 2,000 feet in 5¼ miles. (See Pl. VI, *A* and *B*.) One-half mile above the mouth of West Fork there are falls 15 feet in height. Another drop of about the same height occurs three-fourths mile below the mouth of Little Muddy Creek and there are several falls on Fish Lake Stream, a short distance above its mouth. The grade of the main Klickitat is fairly uniform, averaging 44.5 feet to the mile for the 73 miles surveyed. The dually decreases from 63 feet to the mile below Diamond Fork

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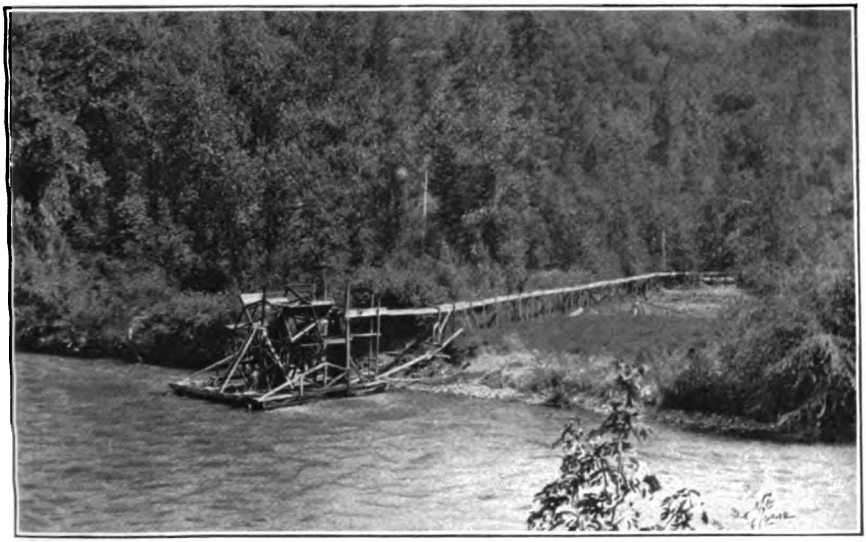
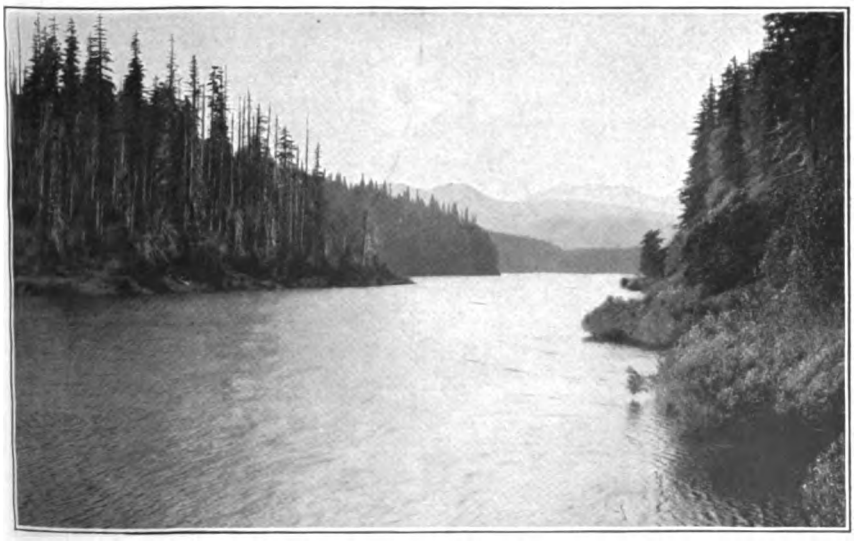


A. IRRIGATION WHEEL ON KLICKITAT RIVER NEAR WRIGHT.



B. LAKE MERRILL, ON LEWIS-KALAMA RIVER DIVIDE.

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A. FALLS ON WEST FORK OF KLICKITAT RIVER.

B. FALLS ON BIG MUDDY RIVER.

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to 20 feet to the mile at the head of the box canyon (Pl. V, *A*). This box canyon continues from a point about half a mile above the lower railroad bridge to the mouth of the river, but the lower 1½ miles are subject to backwater from Columbia River. The canyon has been cut in the solid basalt (Pl. III, *A*), and in places is not over 10 feet in width, with perpendicular sides of jagged rock. The total fall here is 75 feet in three-fourths of a mile. Favorable sites for dams are numerous on the main stream (Pls. VII, *A;* VIII, *A*), and the benches along the river in some places render construction of open canals entirely feasible. On the steep canyon sides, however, water would be more safely carried in large pressure pipes. During warm weather the waters, particularly those from Mount Adams, carry considerable glacial silt which would cut machinery badly.

In computing the water powers in this drainage basin the streams have been considered in sections. The sections are limited by some tributary or otherwise divided in order to keep their length within possible limits of diverting canals or pipe lines. The elevations of the water surface at the extremities of these sections, the total fall, the fall per mile, and the drainage area of each section considered are given below. The discharge at the upper end of the section has been estimated from the data already presented. In determining this discharge an attempt has been made to give an average minimum in the manner previously described. This figure is the most uncertain part of the data, but it is believed to be conservative.

The horsepower given is 70 per cent of the theoretical power that is computed from the known fall in the section and the estimated discharge at its upper extremity. Seventy per cent is, of course, an arbitrary proportion, but it represents very nearly the power on turbine shafts that is actually realized in many plants in operation at the present time.

Water powers in Klickitat River drainage basin.

Point on stream.	Distance above mouth.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Drainage area.	Average minimum discharge.		Available horsepower (70 per cent of theoretical).
							Second-feet.	Second-feet per square mile.	
Klickitat River.									
	Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Sq. miles.*			
Below mouth of Diamond Fork	72.70	3,330	.....	.....	.....	85	80	0.94	.....
Above mouth of McCreedy Creek	67.35	2,995	5.35	335	62.6	110	.....	.....	2,270
Below mouth of McCreedy Creek	67.35	2,995	.....	.....	.....	129	105	.81	.....
Castile Ford	62.15	2,715	5.20	280	53.8	150	120	.80	2,340
Above mouth of West Fork	60.50	2,545	1.65	170	10.3	162	.....	.....	1,600
Below mouth of West Fork	60.50	2,545	.....	.....	.....	254	370	1.46	.....

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Water powers in Klickitat River drainage basin—Continued.

Point on stream.	Distance above mouth.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Drainage area.	Average minimum discharge.		Available horsepower (70 per cent of theoretical
							Second-feet.	Second-feet per square mile.	
Klickitat River—Continued.									
Above mouth of Big Muddy River	*Miles.* 51.85	*Feet.* 1,982	*Miles.* 8.65	*Feet.* 563	*Feet.* 65.1	*Sq. m.* 314			16,[illegible]
Below mouth of Big Muddy River	51.85	1,982				347	590	1.71	
Above mouth of Outlet Creek	37.85	1,155	14.0	827	59.0	441			3[illegible]
Below mouth of Outlet Creek	37.85	1,155				528	790	1.50	
Alvord's Bridge, sec. 12, T. 5, R. 13	30.30	855	7.55	300	39.8	663	800	1.21	1[illegible]
Above mouth of Little Klickitat River	19.55	565	10.75	290	27.0	710			1[illegible]
Below mouth of Little Klickitat River	19.55	565				995	900	.90	
Wright	13.65	445	5.90	120	20.3	1,090	970	.89	[illegible]
Head of box canyon	2.20	150	11.45	295	25.7	1,140	1,000	.88	2[illegible]
Foot of rapids	1.45	75	.75	75	100.0	1,160			[illegible]
West Fork and Fish Lake Stream.									
Head of survey	6.75	3,370				38	120		
Above mouth of Little Muddy Creek	4.42	3,012	2.33	358	15.4	42			[illegible]
Below mouth of Little Muddy Creek	4.42	3,012				83	190		7,[illegible]
Mouth		2,545	4.42	467	10.6	92			
Big Muddy River.									
Below mouth of Hellroaring Creek	3.45	2,950				23	100		
Mouth		1,982	3.45	968	28.1	33			7,700
									154,000

WHITE SALMON RIVER DRAINAGE BASIN.

DESCRIPTION.

White Salmon River has its source in three glaciers on the west side of Mount Adams. The largest of these is White Salmon River Glacier. To the north of this lies Pinnacle Glacier and to the south Avalanche Glacier. The river flows southward and empties its waters into Columbia River at the town of Underwood. The source and mouth of the river lie on the same meridian. The river has a total length of 38.5 miles and a total drainage area of 352 square miles. Plate XI is a map of this drainage area.

Trout Creek is the principal tributary. It drains the high spurs and secondary peaks to the southwest of Mount Adams, flows in a southeasterly direction, and empties into White Salmon River near Trout Lake post-office. Three small creeks—Big Spring Creek from the west and Gilmer and Rattlesnake creeks from the east—empty into the river below Trout Creek in the vicinity of Husum. Gotchen

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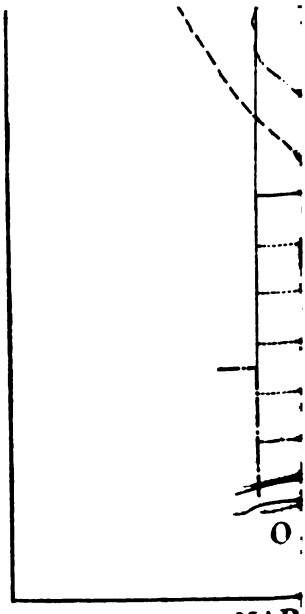

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Creek, the principal tributary above Trout Creek, drains the high spurs to the southeast of Mount Adams.

The drainage area of White Salmon River is distributed as follows:

	Square miles.
Above the mouth of Trout Creek	84
Below the mouth of Gilmer Creek	290
At Husum	300
At Underwood	352
Trout Creek	85

The prominent topographic feature of the area is Mount Adams (Pl. XII, *A*) and the spurs and secondary peaks that surround it. These peaks crown the bounding lines of the drainage area, which is roughly V-shaped with Mount Adams at the apex. On the west Steamboat Mountain (at an elevation of 4,600 feet), the Castle (5,100 feet), and Old Huckleberry (5,200 feet) stand like sentinels on the summit of the divide. South Butte (7,790 feet), Snow Plow (5,070 feet), Snipes Mountain (4,800 feet), King Mountain (4,710 feet), and Snow Mountain (3,620 feet) prominently mark the eastern boundary. The basin is therefore roughly trough-shaped with several smaller peaks within it. The topography is bold and picturesque. The streams flow in deep canyons on beds of bowlders, with here and there ledges of basalt or stretches of box canyons that have vertical jagged sides and solid beds.

The whole drainage basin is covered with lava and basalt, in which the canyons have been carved. Near Mount Adams many cinder cones and bombs give evidence of recent volcanic activity. Red Butte, 3 miles northeast of Mount Adams, has an elevation of 7,203 feet. The cone is 500 feet high, with a crater 175 feet in diameter and 75 feet deep. Much of the pumice, scoria, and lava from these cones is highly colored, and volcanic glass is found in various shades from black masses to transparent globules. The bombs on the lower slopes of Mount Adams are rough spherical masses of lava, of homogeneous texture, ranging up to 30 feet in diameter. Near the headwaters are large areas of partly exposed lava beds. A line of caves may be traced along this formation for 20 miles or more. In some places the caves have been formed by the liquid mass flowing from under a solidified crest; in others they may have resulted from the action of gases and are in effect huge bubbles. One of these in sec. 25, T. 6 N., R. 9 E is widely known as the Ice Cave. The temperature is so low that water accumulating and freezing during the winter does not thaw out during the following summer. The ice is found in masses on the floor and in stalactites and stalagmites formed by surface water dripping through crevices in the roof. These form during the winter and are partly melted during the sum-

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mer. The area in which these caves lie is drained by Trout Creek. The basin contains several small intermittent watercourses in which the water sinks at many points. It is likely that much of the surface water finds its way deep into these lava beds, emerging into lower portions of White Salmon River or even into the adjacent drainage basin of Little White Salmon River.

The main river flows in a deep canyon whose sides are bordered by heavily rolling table-lands or mountains. From a point 3 miles below Trout Creek to a point 2½ miles above Husum the river flows in a narrow box canyon. This has been cut squarely into the basalts and the recent lava flows that have overspread them. The canyon is about 11 miles long and nearly every part of it would afford a favorable site for a dam. Trout Creek, on the other hand, is essentially a surface stream below Trout Lake. The banks are bordered by fairly level stretches of open meadows and agricultural land.

The north line of T. 6 N. forms the southern boundary of the Columbia National Forest. Logging operations have been carried on for years in this drainage area, for the most part on lands adjacent to the river (Pl. V, *B*, p. 44). The entire drainage area is heavily forested except where cleared for agriculture. Within the national forest the timbered area constitutes 73 per cent of the total, 26 per cent is burned, and 1 per cent is above timber line. The species are distributed in about the same proportion as those in the adjacent Klickitat basin, except that there is more red or yellow fir and less yellow pine. The stand of timber within the national forest is about as follows:

	Per cent.
0 to 2,000 feet b. m. per acre	18
2,000 to 5,000 feet b. m. per acre	30
5,000 to 10,000 feet b. m. per acre	40
10,000 to 25,000 feet b. m. per acre	8
25,000 to 50,000 feet b. m. per acre	4

There are no railroads in the drainage area except the Spokane, Portland and Seattle Railway which crosses the river at its mouth in its course along the right bank of Columbia River. The principal towns are Underwood and White Salmon, the latter being on the high table-land east of the river near its mouth. Husum post-office is at the mouth of Rattlesnake Creek. Trout Lake post-office is near the mouth of Trout Creek, on the east side of the river, and Guler is on Trout Creek near the outlet of Trout Lake. Good wagon roads and stage lines connect all the towns. The upper portion of this area is a favorite summer resort, and many campers will be found around Trout Lake and Guler in the summer.

The rolling benches along the lower part of the river have been cleared for agriculture. Most of these lands are in orchards and the

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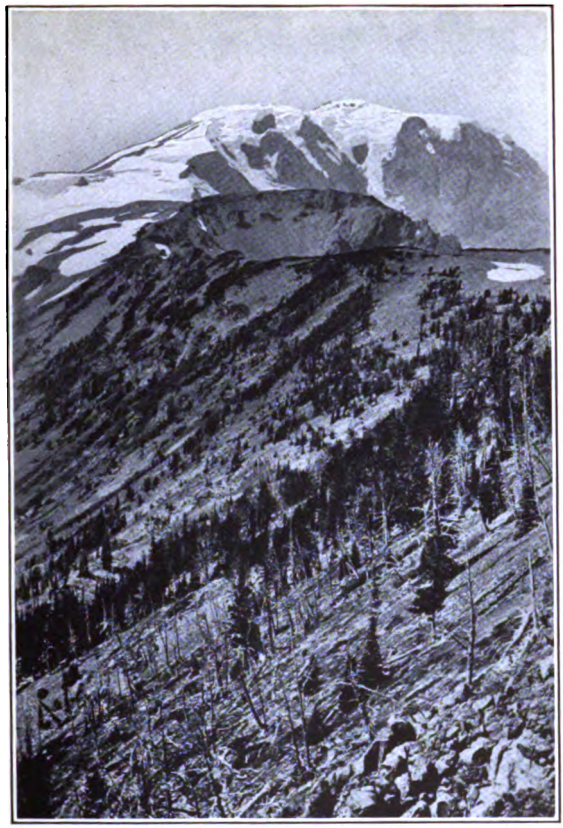

A. MOUNT ADAMS FROM THE SOUTHEAST.

B. MOUNT ST. HELENS FROM THE NORTHEAST.

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territory has become justly famous for the excellent quality of its apples and other fruit. In T. 6 N. the lands along the river are comparatively flat and some of them were natural meadows. These open lands have been enlarged by clearing the timber around them and the whole valley presents a delightful picture of prosperity. In this portion of the valley irrigation is practiced extensively. The water for the ditches is diverted from Trout Creek and White Salmon River. These ditches are small but numerous and they have an abundant supply of water.

At present lumbering is the principal industry of this territory. The Wind River Lumber Company has constructed several splash dams on White Salmon River by means of which logs are floated from the upper portion of the drainage area to the mouth of the river, when they are gathered and transported in rafts to the mills on the lower Columbia.

At Husum is a small power plant owned and operated by the Husum Power Company. The present capacity of the plant is 200 horsepower. It is developed by a Sampson twin turbine with 26-inch wheels, belt connected to a 75-kilowatt General Electric alternator, generating at 2,300 volts. Current is transmitted to White Salmon, 6½ miles, and up the valley 2 miles, for lighting and power. The water is supplied to the wheels by a canal 200 feet in length. The canal normally carries 120 second-feet and develops a head of 17 feet around falls in the river at this point.

So far as known, the basin affords no large reservoir sites. Trout Lake is the only flat area that would be suitable, but the outlet is a broad valley and no favorable dam sites are found. Most of the water runs off during the spring, exposing the lake bed as a marshy flat. A small amount of storage might be developed at Steamboat Lake near the headwaters of Trout Creek.

Owing to the porous lava rocks of which the area is composed and the soil resulting from its disintegration, a large amount of water is held in ground storage. Springs are numerous along the river and seepage into it is large. Most of the summer flow, however, is supplied by the glaciers on Mount Adams. Above Trout Creek, White Salmon River has its lowest discharge during cold weather, while on hot summer days the discharge is high and the water is heavily loaded with glacial silt. Trout Creek, on the other hand, has its lowest period at the end of the summer season. During the winter months the discharge is relatively high from surface drainage from the large area through which it flows. The two streams, therefore, maintain a well-balanced flow during the year. Floods occur during heavy rains when accompanied by chinook winds, which suddenly melt the snow on the hills. The heaviest floods are likely to occur in the

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autumn after an early snowfall. A flood from this cause of greater or less magnitude may be expected about the middle of each November and at other times during the winter months. Spring floods occur periodically, but are rarely so severe as the fall floods and are not so sudden. These result from the more gradual melting of snow in the mountains as warm weather approaches. This melting is arrested at night, with the result that the stream shows daily variations of considerable magnitude.

No discharge data are available except those gathered during the course of the survey in the summer of 1909. Measurements were made at several points on the main stream and its tributaries. Two permanent gaging stations were established, on Trout Creek at Guler and on White Salmon River at Husum.

WHITE SALMON RIVER AT HUSUM.

This station was established September 23, 1909. The gage is a vertical staff on the right bank 1,200 feet above the bridge at Husum and above the power-canal intake. No permanent equipment was installed for making measurements at high stages.

On account of the extensive and continual use of the stream for floating logs, the gage heights are more or less affected by backwater when they lodge in the channel. (See Pl. V, *B*.)

A discharge measurement was made September 23, 1909, by H. D. McGlashan:

Gage height, 3.12 feet; area, 249 square feet; mean velocity, 2.61 feet per second; discharge, 650 second-feet.

Daily gage height, in feet, of White Salmon River at Husum, Wash., for 1909.

Day.	Sept.	Oct.	Nov.	Dec.	Day.	Sept.	Oct.	Nov.	Dec.
1		2.85	3.12	5.85	16		3.03	3.15	4.12
2		3.00	4.15	5.10	17		3.00	3.14	4.10
3		3.00	5.90	4.80	18		3.00	3.95	4.06
4		3.10	6.20	4.65	19		3.00	6.35	4.03
5		3.10	4.25	4.45	20		3.05	6.80	4.02
6		2.90	3.80	4.33	21		3.10	4.90	4.00
7		2.90	3.50	4.20	22		3.00	5.25	3.90
8		3.00	3.52	4.12	23		3.05	7.30	3.90
9		2.95	3.70	4.01	24	3.10	3.08	7.65	3.90
10		3.05	3.60	3.98	25	3.10	3.06	5.90	3.88
11		3.08	3.45	3.96	26	3.06	3.00	5.20	3.85
12		3.00	3.30	4.16	27	3.00	2.92	4.80	3.83
13		2.90	3.21	4.60	28	3.10	2.96	4.75	3.80
14		2.90	3.20	4.45	29	3.05	3.12	5.25	3.75
15		2.95	3.18	4.20	30	3.25	3.10	7.30	3.85
					31		3.18		3.85

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Daily discharge, in second-feet, of White Salmon River at Husum, Wash., for 1909.

Day.	Sept.	Oct.	Day.	Sept.	Oct.	Day.	Sept.	Oct.
1		510	11		629	21		640
2		585	12		585	22		585
3		585	13		535	23		612
4		640	14		535	24	640	629
5		640	15		560	25	640	618
6		535	16		602	26	618	585
7		535	17		585	27	585	545
8		585	18		585	28	640	565
9		560	19		585	29	612	651
10		612	20		612	30	722	640
						31		684

TROUT CREEK AT GULER.

This station was established September 16, 1909.

The gage is a vertical staff located 500 feet below the highway bridge on the left bank. The station is above all diversions for irrigation. Measurements are made by wading or from the bridge at high stages. The conditions are favorable for good results, and the data will be valuable for irrigation and general statistical purposes.

A measurement was made September 16, 1909, by H. D. McGlashan:

Gage height, 1.32 feet; area, 34 square feet; mean velocity, 1.38 feet per second; discharge, 47 second-feet.

Daily gage height, in feet, of Trout Creek at Guler, Wash., for 1909.

Day.	Sept.	Oct.	Nov.	Dec.	Day.	Sept.	Oct.	Nov.	Dec.
1		1.58	2.61	7.00	16	1.32	1.32	2.90	4.00
2		1.41	4.10	6.41	17	1.32	1.32	3.10	4.00
3		1.41	6.71	6.05	18	1.32	1.32	3.60	4.00
4		1.41	6.25	5.25	19	1.34	1.39	6.00	3.76
5		1.72	4.66	5.00	20	1.55	1.74	5.55	3.76
6		1.74	4.32	4.75	21	1.64	1.96	5.00	3.75
7		1.73	4.32	4.53	22	1.52	1.87	4.62	3.75
8		1.64	4.34	4.31	23	1.45	1.75	5.30	3.73
9		1.54	5.00	4.30	24	1.36	1.72	6.00	3.70
10		1.46	4.72	4.30	25	1.38	1.65	7.16	3.70
11		1.38	3.40	4.30	26	1.35	1.55	6.42	3.65
12		1.38	2.80	4.41	27	1.32	1.55	5.15	3.63
13		1.37	2.80	4.40	28	1.32	1.54	4.86	3.50
14		1.36	2.75	4.34	29	1.50	1.64	5.52	3.50
15		1.33	2.82	4.30	30	1.61	2.15	6.25	3.20
					31		2.20		3.00

Daily discharge, in second-feet, of Trout Creek at Guler, Wash., for 1909.

Day.	Sept.	Oct.	Day.	Sept.	Oct.	Day.	Sept.	Oct.
1		70	11		52	21	76	114
2		55	12		52	22	65	101
3		55	13		52	23	58	88
4		55	14		51	24	51	84
5		84	15		48	25	52	77
6		86	16	48	48	26	50	68
7		85	17	48	48	27	48	68
8		76	18	48	48	28	48	67
9		67	19	49	53	29	63	76
10		59	20	68	86	30	73	147
						31		157

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MISCELLANEOUS MEASUREMENTS.

Miscellaneous discharge measurements were made in this basin as shown in the following table. The normal capacities of irrigation ditches diverting water from White Salmon River and Trout Creek were also determined from the quantity carried at the time of making the survey.

Miscellaneous measurements in White Salmon River basin, 1909.

[By H. D. McGlashan.]

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
			Feet.	*Sq. feet.*	*Ft. per sec.*	*Sec.-feet.*
September 11...	Unnamed [a]	Mouth (estimated)				1.5
Do	Unnamed [b]	do				10
September 13...	Gotchen Creek	do				25
Do	Unnamed [c]	do				1
Do	White Salmon River [d]	Sheep bridge	28	56	3.68	206
September 23...	Gilmer Creek	Mouth (dry)				0
September 24...	Rattlesnake Creek	Mouth (estimated)				2
Do	Big Spring Creek	do				10
September 25...	Little Buck Creek	do				4
Do	Unnamed [e]	do				1

[a] Tributary from left 4.8 miles above boundary line of national forest.
[b] Tributary from left 3.8 miles above boundary line of national forest.
[c] Tributary from right 1 mile above boundary line of national forest.
[d] Water surface 2.05 feet below 10-penny nail in stream face of small alder on left bank 100 feet below bridge at trail crossing 1 mile above boundary line of national forest.
[e] Tributary from left 3.5 miles above mouth of White Salmon River.

Irrigation ditches in White Salmon River drainage basin.

DIVERTING WATER FROM WHITE SALMON RIVER.

Name of ditch.	Location of head-gate.	Bank of stream.	Approximate capacity.
			Sec.-feet.
Wagnitz	NE. ¼ sec. 3, T. 6, R. 10	Right	3
Thomas	NW. ¼ sec. 14, T. 6, R. 10	do	2
Coats and Duncan	do	Left	10
Coats Bros	SE. ¼ sec. 14, T. 6, R. 10	do	5
Dutch	do	do	5
Pearson	do	do	5
Huber	SE. ¼ sec. 24, T. 6, R. 10	Right	3
Trout Lake	NE. ¼ sec. 31, T. 6, R. 11	Left	25

DIVERTING WATER FROM TROUT CREEK.

McDonald	NE. ¼ sec. 22, T. 6, R. 10	Right	8
Pearson-Thompson	do	do	7

AVERAGE MINIMUM DISCHARGE.

From the foregoing data the following table has been compiled. The average minimum for the Husum and Guler stations is taken as the mean discharge for the lowest week and is arbitrarily increased 20 per cent, as explained on page 31. The miscellaneous measurements have been used in combination with the data obtained at the gaging stations in estimating the average minimum discharge at other

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points on the stream. Allowance has also been made for intervening accretions to the flow, as indicated by springs or tributaries. No allowance has been made for ditches diverting water, as the aggregate diversion is but a small portion of the total discharge of the main streams.

For the portion above Trout Creek the winter minimums would govern power development; below Trout Creek the summer minimums would govern, as Trout Creek would be enough higher during the winter low-water period to more than balance the reduced flow in the main stream due to cold weather.

Average minimum discharge for White Salmon River drainage basin.

Locality.	Drainage area.		Date.	Measured discharge.	Adjusted average minimum.
	Square miles.	Per cent of total.			
White Salmon River:				*Sec.-feet.*	*Sec.-feet.*
Head of survey	37	10	Winter		100
Boundary Columbia National Forest.	69	20	.....do		150
Below Trout Creek	169	48	October		470
Splash dam, sec. 6, T. 5, R. 11	256	73	.....do		660
Falls, sec. 25, T. 5, R. 10	266	75	.....do		670
Below Gilmer Creek	290	82	.....do		700
Husum gaging station	300	85	October 18, 1909	590	710
North line sec. 10, T. 3, R. 10	337	96	October		770
Trout Creek, Guler gaging station	82	.....	October 18, 1909	50	60

WATER POWERS.

Owing to the steep grade, well-maintained summer flow, and rocky canyons through which White Salmon River flows, opportunities for water-power developments are abundant. The average fall of the main river for that portion surveyed—32.1 miles—is 83 feet to the mile. Nine miles of the river's course above the mouth of Gilmer Creek has an average fall of 117 feet to the mile; in the last 3 miles the fall averages 53 feet to the mile. Trout Creek falls 115 feet from Trout Lake to its mouth, somewhat more than 2 miles. Where the north line of sec. 25, T. 5, R. 10, crosses White Salmon River there are two falls with a total drop of 35 feet. At Husum there is a drop of 15 feet, and at a point 4 miles above the boundary of the national forest there is a drop of 5 feet.

The Wind River Lumber Company has splash dams for floating logs in sec. 14, T. 6, R. 10; sec. 6, T. 5, R. 11; and sec. 14, T. 3, R. 10. The waters of the river are used extensively for this purpose, and doubtless certain water rights have attached.

Power developments could best take the form of pipe or open-canal diversion for high heads. In computing the water powers in this area, therefore, the streams are divided into sections of a length that would probably represent feasible lengths for open canals or pressure pipes.

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The elevations of the water surface at the extremities of these sections, the total fall, the fall per mile, and the drainage area are given below for each section considered. The discharge at the upper end of the section has been estimated from the data presented above. In determining this discharge an attempt has been made to give an average minimum in the manner already described. This figure is the most uncertain part of the data, but it is believed to be conservative.

The horsepower given is 70 per cent of the theoretical power that is computed from the known fall in the section and the estimated discharge at its upper extremity. Seventy per cent is of course an arbitrary proportion, but it represents very nearly the power on turbine shafts that is actually realized in many plants in operation at the present time.

Water powers in White Salmon River drainage basin.

Point on stream.	Distance above mouth.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Drainage area.	Average minimum discharge.		Available horsepower (70 per cent of theoretical).
							Second-feet.	Second-feet per square mile.	
Main stream.	*Miles.*	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Square miles.*			
Head of survey	32.10	2,705	.....	.....	.....	37	100	2.7	4,020
Boundary Columbia National Forest	28.60	2,200	3.50	505	143	69	150	2.2	3,700
Above mouth of Trout Creek	24.55	1,890	4.05	310	76.5	84	.....	.....	.....
Below mouth of Trout Creek	24.55	1,890	.....	.....	.....	169	470	2.8	10,100
Splash dam in sec. 6, T. 5, R. 11	20.32	1,620	4.23	270	63.9	256	660	2.6	28,900
Foot of falls, sec. 25, T. 5, R. 10	15.60	1,070	4.72	550	117	266	670	2.5	22,400
Below mouth of Gilmer Creek	12.00	650	3.60	420	117	290	700	2.4	16,200
Husum bridge	7.40	360	4.60	290	63	300	710	2.4	8,500
North line sec. 10, T. 3, R. 10	3.12	210	4.28	150	35	337	770	2.3	10,100
Underwood (mouth)	.....	45	3.12	165	52.9	352	.....	.....	.....
Trout Creek.									
Guler	2.15	2,005	.....	.....	.....	82	60	.70	.....
Mouth	.....	1,890	2.15	115	53.5	85	.....	.....	550
									105,000

LITTLE WHITE SALMON RIVER DRAINAGE BASIN.

DESCRIPTION.

Little White Salmon River drains the extreme south end of the Cascade Range in Washington. It lies between the main summit of this range and the White Salmon River drainage basin. The river rises on Old Huckleberry Mountain, at an elevation of 5,200 feet, flows almost directly south, and empties into Columbia River near the town of Cooks, 6½ miles downstream from the mouth of White Salmon River. The principal tributaries enter from the west, and in order downstream are Moss Creek, Lava Creek, and Rock Creek. The main river has a total length of 17 miles and a total drainage area of

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132 square miles. The drainage area above Moss Creek is 37 square miles, and at a point below the mouth of Lava Creek 110 square miles. Lava Creek drains 72 square miles. Plate XI shows this drainage area.

The general topographic features of the country are similar to those of the territory drained by White Salmon River. Old Huckleberry, the highest mountain, has no well-defined summit, but is rather an elongated ridge with projecting spurs to the north and south. The area is rough and mountainous. The stream flows in a very deep canyon with steep and rugged sides. There are benches paralleling the river several hundred feet above the water surface for a portion of its length. The immediate valley is occupied almost entirely by the stream, the flood plain being very narrow.

The forests on this area are similar to those in the Klickitat and White Salmon drainage basins, previously described, except that the stand is heavier and the species show the change from a semiarid to a humid climate.

The southern boundary of the Columbia National Forest crosses the river about 7 miles above its mouth. Within this area 93 per cent of the land is covered with forest and 7 per cent has been burned. Nearly all of the burned areas are being restocked, and the forest cover has been established. About 55 per cent of the stand of timber is red and yellow fir, 10 per cent hemlock, 10 per cent red cedar, 5 per cent white pine, 5 per cent yellow pine, and 15 per cent other species. The average stand of timber for this drainage area is over 4,000 board measure per acre; 24 per cent of the area has a stand of less than 2,000 feet board measure per acre, 60 per cent from 2,000 to 5,000 feet, 7 per cent from 5,000 to 10,000 feet, and 9 per cent from 10,000 to 25,000 feet.

There are no railroads in the drainage area except one which crosses the river at its mouth. A wagon road follows the main river from Crooks to the head of the stream. Agriculture is not extensively practiced, although a few small tracts, mainly on bench lands along the river, have been cleared and planted to crops. On the right bank, 3 miles above the mouth, there is a bench containing over 600 acres. The timber on this bench has been logged and the land is now on the market at $150 an acre. The conditions are favorable for raising fruit. On the opposite side of the river is another narrow bench extending for several miles upstream. These lands would doubtless raise fruit of good quality if cleared. It is estimated that there are 30,000 acres of land in the Little White Salmon River drainage area suitable for agriculture after the timber has been removed.

The principal industry at present is lumbering. Large quantities of timber have already been cut from the area outside of the national forest. The logs removed are generally hauled by wagon down the

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canyon road. One mill is in operation at present 3 miles above the mouth. The sawed lumber is floated in a flume to Columbia River.

No discharge data has been gathered on this stream by the Geological Survey other than those procured at the time of making the river survey. The river is subject to heavy floods during the fall and winter, and the summer discharge is comparatively low. During the summer months the principal source of supply is Moss Creek. Though this stream is not long, it is probably well supplied with water from underground sources. Lava Creek is an intermittent stream flowing through lava beds, and although its drainage area is comparatively large, a large proportion of the water falling upon its sinks into the ground, probably to reappear at points farther down. It is very likely that Moss Creek receives considerable water from the territory through which Lava Creek flows.

LITTLE WHITE SALMON RIVER BELOW LAVA CREEK.

From 1903 to 1906 the Portland Railway, Light and Power Company made determinations of discharge of Little White Salmon River below Lava Creek. A rectangular weir, 16.2 feet in length, was installed and daily records kept. Through the courtesy of the company these records are given in the following table:

Daily discharge, in second-feet, of Little White Salmon River below the mouth of Lava Creek for 1903–1906.

Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.
1903.			1903.			1903.		
1		(a)	11	275	278	21	278	(a)
2		(a)	12	270	268	22	278	(a)
3	89	(a)	13	278	277	23	278	(a)
4	135	(a)	14	266	277	24	278	(a)
5	185	(a)	15	266	277	25	278	(a)
6	225	(a)	16	257	290	26	278	(a)
7	275	303	17	257	302	27	303	(a)
8	220	303	18	257	315	28	325	300
9	235	278	19	265	325	29	315	280
10	220	268	20	245	(a)	30	370	353
						31		353

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.												
1	328	(a)	(a)	(a)	(a)	(a)	(a)	264	187	92	54	315
2	328	340	(a)	(a)	(a)	(a)	(a)	256	180	87	54	315
3	317	340	(a)	(a)	(a)	(a)	(a)	254	180	87	52	315
4	317	328	(a)	(a)	(a)	(a)	(a)	246	170	86	50	295
5	317	327	(a)	(a)	(a)	(a)	(a)	243	170	80	48	278
6	317	328	(a)	(a)	(a)	(a)	(a)	235	160	80	44	256
7	300	328	(a)	(a)	(a)	(a)	(a)	234	160	77	44	254
8	315	339	(a)	(a)	(a)	(a)	(a)	224	160	76	44	254
9	326	340	(a)	(a)	(a)	(a)	(a)	220	150	75	44	254
10	230	351	(a)	(a)	(a)	(a)	(a)	210	150	74	44	254
11	275	328	(a)	(a)	(a)	(a)	(a)	210	138	94	44	270
12	300	328	(a)	(a)	(a)	(a)	(a)	210	138	83	44	300
13	(a)	315	(a)	(a)	(a)	(a)	(a)	199	138	75	47	330
14	(a)	300	(a)	(a)	(a)	(a)	(a)	199	138	72	48	(a)
15	(a)	280	(a)	(a)	(a)	(a)	(a)	198	128	69	50	(a)

a Discharge more than 350 second-feet; water flowing around weir.

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Daily discharge, in second-feet, of Little White Salmon River below the mouth of Lava Creek for 1903–1906—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.												
16	(a)	280	(a)	(a)	(a)	(a)	(a)	190	128	68	53	(a)
17	(a)	302	(a)	(a)	(a)	(a)	(a)	190	117	68	54	208
18	(a)	316	(a)	(a)	(a)	(a)	(a)	190	110	64	57	(a)
19	(a)	327	(a)	(a)	(a)	(a)	350	179	110	64	60	(a)
20	(a)	350	(a)	(a)	(a)	(a)	328	179	110	64	350	(a)
21	(a)	338	(a)	(a)	(a)	(a)	328	168	110	60	280	(a)
22	(a)	328	340	(a)	(a)	(a)	316	168	110	60	280	(a)
23	(a)	340	(a)	(a)	(a)	(a)	316	168	104	60	178	(a)
24	(a)	350	(a)	(a)	(a)	(a)	314	160	104	58	178	(a)
25	(a)	340	(a)	(a)	(a)	(a)	303	160	104	63	178	(a)
26	(a)	315	(a)	(a)	(a)	(a)	303	150	104	58	178	(a)
27	(a)	327	(a)	(a)	(a)	(a)	290	150	93	57	250	(a)
28	(a)	350	(a)	(a)	(a)	(a)	290	168	93	57	244	(a)
29	(a)	.....	(a)	350	(a)	(a)	276	168	93	56	248	(a)
30	(a)	.....	(a)	340	(a)	(a)	276	185	92	54	300	(a)
31	(a)	.....	(a)	329	(a)	.....	267	180	.....	54	.....	(a)
1905.												
1	(a)	340	(a)	.....	.....	.....	.....	.....	40	26	44	63
2	(a)	325	(a)	.....	.....	.....	.....	.....	40	26	43	67
3	(a)	327	(a)	.....	.....	.....	.....	.....	40	30	41	73
4	(a)	330	(a)	.....	.....	.....	.....	.....	37	40	40	77
5	(a)	316	(a)	.....	.....	.....	.....	.....	36	40	40	78
6	(a)	316	(a)	.....	.....	.....	.....	.....	36	38	39	92
7	(a)	325	(a)	.....	.....	.....	.....	.....	34	60	38	127
8	(a)	330	340	.....	.....	.....	.....	.....	34	60	37	146
9	(a)	330	336	.....	.....	.....	.....	.....	30	50	36	130
10	(a)	336	336	.....	.....	.....	.....	.....	30	46	36	120
11	(a)	340	336	.....	.....	.....	.....	.....	30	41	36	113
12	(a)	318	336	.....	.....	.....	.....	.....	37	37	36	105
13	350	304	337	.....	.....	.....	.....	.....	34	38	36	103
14	338	304	228	.....	.....	.....	.....	.....	34	39	36	100
15	338	290	226	.....	.....	.....	.....	.....	34	45	35	98
16	338	270	226	.....	.....	.....	.....	.....	33	45	34	126
17	329	158	226	.....	.....	.....	.....	.....	33	47	34	220
18	328	158	(b)	.....	.....	.....	.....	.....	28	50	33	245
19	328	240	.....	.....	.....	.....	.....	.....	27	50	93	265
20	328	240	.....	.....	.....	.....	.....	54	27	50	87	267
21	317	250	.....	.....	.....	.....	.....	54	27	48	75	250
22	323	335	.....	.....	.....	.....	.....	54	28	47	64	235
23	353	158	.....	.....	.....	.....	.....	50	28	48	60	195
24	353	350	.....	.....	.....	.....	.....	46	28	49	57	135
25	340	(a)	.....	.....	.....	.....	.....	46	28	50	53	215
26	340	(a)	.....	.....	.....	.....	.....	46	34	48	60	312
27	(a)	(a)	.....	.....	.....	.....	.....	46	30	50	60	308
28	(a)	(a)	.....	.....	.....	.....	.....	46	28	47	60	310
29	(a)	.....	.....	.....	.....	.....	.....	46	27	46	62	309
30	(a)	.....	.....	.....	.....	.....	.....	43	26	44	63	270
31	(a)	.....	.....	.....	.....	.....	.....	40	.....	44	.....	230
1906.												
1	210	(a)	(a)	.....	290	280	242	129	.....	.....	.....	.....
2	190	(a)	(a)	350	290	280	239	140	.....	.....	.....	.....
3	182	(a)	(a)	320	289	279	233	138	.....	.....	.....	.....
4	190	338	(a)	323	288	279	230	135	.....	.....	.....	.....
5	195	328	(a)	320	287	276	227	132	.....	.....	.....	.....
6	220	313	(a)	342	287	275	222	.....	.....	.....	.....	.....
7	245	300	(a)	336	285	274	218	.....	.....	.....	.....	.....
8	246	288	(a)	338	284	272	214	.....	.....	.....	.....	.....
9	250	280	(a)	350	283	271	210	.....	.....	.....	.....	.....
10	238	268	(a)	340	283	271	209	.....	.....	.....	.....	.....
11	240	264	(a)	332	282	270	207	.....	.....	.....	.....	.....
12	230	255	(a)	328	281	268	200	.....	.....	.....	.....	.....
13	237	245	(a)	320	281	270	197	.....	.....	.....	.....	.....
14	225	242	(a)	320	285	275	193	.....	.....	.....	.....	.....
15	212	240	345	320	294	283	190	.....	.....	.....	.....	.....

a Discharge greater than 350 second-feet; water flowing around weir.
b No record March 18 to August 19, 1905.

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Daily discharge, in second-feet, of Little White Salmon River below the mouth of Lava Creek for 1903–1906—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1906.												
16	214	237	330	320	290	280	186					
17	220	240	315	316	284	274	180					
18	218	(a)	305	314	284	269	177					
19	210	(a)	270	311	282	267	172					
20	195	(a)	255	310	281	267	169					
21	193	(a)	260	310	280	266	166					
22	198	(a)	267	309	280	262	164					
23	350	(a)	273	309	280	260	163					
24	(a)	(a)	278	307	280	256	157					
25	(a)	(a)	289	303	280	254	152					
26	(a)	(a)	305	297	280	252	148					
27	(a)	(a)	310	294	280	248	145					
28	(a)	(a)	304	293	280	245	142					
29	(a)		303	291	280	244	140					
30	(a)		350	291	280	243	135					
31	(a)				280		130					

a Discharge greater than 350 second-feet; water flowing around weir.

LITTLE WHITE SALMON RIVER NEAR COOKS.

This temporary station was established October 4, 1909. It is located at the fish hatchery one-half mile above the mouth of the river. The gage is a vertical staff spiked to the right abutment of a bridge supporting an old lumber flume 200 feet below the fish hatchery. Measurements are made by wading a short distance below the gage. No permanent equipment has been installed for making measurements at high stages, as at such times the station is not beyond influences of backwater from Columbia River. A discharge measurement was made October 4, 1909:

Gage height, 2.09 feet; area, 136 square feet; mean velocity, 1.25 feet per second; discharge, 170 second-feet.

Daily gage height, in feet, of Little White Salmon River near Cooks, Wash., for 1909.

Day.	Oct.	Nov.	Day.	Oct.	Nov.	Day.	Oct.	Nov.
1		3.16	11	2.05		21	2.05	
2		2.90	12	2.04		22	2.07	
3		2.82	13	2.04		23	2.04	
4	2.10	2.72	14	2.02		24	2.02	
5	2.09	2.68	15	2.02		25	2.00	
6	2.08	2.58	16	2.01		26	2.00	
7	2.08	2.49	17	2.00		27	1.98	
8	2.08	2.42	18	2.00		28	1.98	
9	2.07	2.38	19	2.00		29	1.98	
10	2.06	2.54	20	2.02		30	2.04	
						31	2.08	

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Daily discharge, in second-feet, of Little White Salmon River near Cooks, Wash., for 1909.

Day.	Oct.	Nov.	Day.	Oct.	Nov.	Day.	Oct.	Nov.
1	.....	249	11	164	.....	21	164	.....
2	.....	.....	12	163	.....	22	167	.....
3	.....	.....	13	163	.....	23	163	.....
4	171	.....	14	161	.....	24	161	.....
5	170	.....	15	161	.....	25	158	.....
6	168	.....	16	159	.....	26	158	.....
7	168	.....	17	158	.....	27	155	.....
8	168	.....	18	158	.....	28	155	.....
9	167	.....	19	158	.....	29	155	.....
10	166	.....	20	161	.....	30	163	.....
						31	168	.....

MISCELLANEOUS MEASUREMENTS.

The following miscellaneous discharge measurements were made in the basin of Little White Salmon River in 1909:

Miscellaneous discharge measurements, Little White Salmon River Basin, 1909.

[By H. D. McGlashan.]

Date.	Stream.	Locality.	Width.	Area of section.	Mean veloc.	Discharge.
			Feet.	*Sq. ft.*	*Ft. per sec.*	*Sec.-ft.*
October 3	Little White Salmon	Above Moss Creek	23	33	0.39	13
Do	do.[a]	Below Moss Creek	36	61	.72	44
Do	do.[b]	Below Lava Creek	29	67	.69	46
Do	Lava Creek	Mouth	10	8.5	.42	3.6

[a] Water surface 2.66 feet below 10-penny nail in stream face of upstream pile in left abutment of bridge.
[b] Made near weir installed by Portland Railway, Light, and Power Company. Length of weir 16.2 feet head on weir, 0.91 foot; computed discharge, 47.2 second-feet.

AVERAGE MINIMUM DISCHARGE.

From the foregoing data the mean discharge for the lowest week of each year is found to be as follows: Week ending November 12, 1904, 44 second-feet; week ending September 25, 1905, 28 second-feet. Increasing the discharge for 1905 by 20 per cent gives 34 second-feet as a probable value for the average minimum discharge at this point. The measurement made October 3, 1909, gave 46 second-feet, but the river fell considerably lower at the end of October. The mean discharge at the Cooks gaging station was 159 second-feet for the lowest week, ending October 29. This is 6 per cent lower than the gaging of October 3 at that point. The discharge below Lava Creek was doubtless lower on October 29 than on October 3 by a much greater percentage. The increase in discharge from Lava Creek to the mouth is due to numerous springs in the lava beds through which the river flows. As the stream has a small drainage area its flow can not be expected to follow the general tendencies observed for larger areas. The effect of lava beds is an unknown and undeterminable factor in controlling stream flow.

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The discharge of Lava Creek was found to be less th
feet on October 3, yet the stream has a topographic d
of 72 square miles. Moss Creek, on the other hand, is
long, yet the discharge at the same time was found to b
feet by measurements of the main stream above and belo
The porous texture of the lavas that cover these are
vitiate any and all laws of stream discharge when expres
of drainage area.

WATER POWERS.

This stream affords an opportunity for a comparat
plant under a high head. It is likely that during nine m
year considerable power could be developed, but in t
season the water supply is too small for a plant of larg
If developed, water would be diverted below the mout
Creek and carried about 6 miles along the side of the c
pressure pipe. In this manner over 1,100 feet of head
utilized.

The discharge of the main river increases rapidly d
owing to numerous springs. A second pipe line divert
below the mouth of Rock Creek could be used to carry wa
same power house at the mouth of the stream. On this
following power table has been compiled, an estimate
minimum discharge of 120 second-feet being used for
stream below Rock Creek, all of which is inflow below Lava

Water powers in Little White Salmon River drainage basin.

Point on stream.	Distance above mouth.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Drainage area.	Average minimum discharge.	
							Second-feet.	Second-feet per sq. mi.
	Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Sq. mi.*		
Below mouth of Moss Creek	8.1	1,330	.....	.....	.....	37	30	0
Above mouth of Lava Creek	6.1	1,235	2.0	105	52.5	38	.....	.....
Below mouth of Lava Creek	6.1	1,235	.....	.....	.....	110	34	.....
Fish hatchery	.5	45	5.6	1,190	213	132	.....	.....
Below mouth of Rock Creek	3.5	590	.....	.....	.....	120	120	1.
Fish hatchery	.5	45	3.0	545	182	132	.....	.....

LEWIS RIVER DRAINAGE BASIN.

DESCRIPTION.

Lewis River has its source in Adams Glacier, on the no
slope of Mount Adams, flows in a general southwesterly di
and empties into Columbia River 19 miles below Vancouver,

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Its lower half forms the boundary line between Cowlitz and Clarke counties, Wash.; its upper half is entirely within Skamania County. Plate XIII is a map of this drainage area. The total length of the main river is 110 miles, and the stream drops 7,900 feet in that distance.

The principal tributaries in order downstream are, from the north, Muddy River, Pine Creek, Swift Creek, Cougar Creek, and Speilei Creek; from the south, Drift Creek, Siouxon Creek, Canyon Creek, Cedar Creek, and South Fork. Of these South Fork has the largest drainage area, but contributes a relatively small portion of the flow. Muddy River and Pine and Swift creeks supply a large part of the tributary discharge.

The total area drained by Lewis River is 1,070 square miles, distributed as follows:

	Square miles.
Above mouth of Muddy River	250
Above mouth of Swift Creek	474
Below mouth of Cougar Creek	552
At Ariel	728
Above the mouth of South Fork	860
At mouth	1,070
Muddy River	121
Pine Creek	21
Swift Creek	26
Cougar Creek	6
South Fork	195

Mount Adams, 12,307 feet high, and Mount St. Helens (Pl. XII, *A* and *B*), 9,750 feet (height not accurately determined), are the prominent topographic features of this territory. Mount Adams is just to the east of the summit of the Cascade Range and Mount St. Helens is 35 miles almost due west from Mount Adams and 14 miles southwest from the nearest point on the divide. Other peaks are Steamboat Mountain (4,600 feet) and The Castle (5,100 feet), standing southwest of the headwaters. Powderhorn Peak is near the mouth and north of the river.

The area is characterized by rough mountains and by ridges and spurs from the higher peaks. Toward the summit of the range the country becomes more abrupt and rugged. The streams all flow in canyons. In the upper portions the canyon sides are steep and rugged; in the lower stretches there are high benches of fairly level land and valleys of small extent bordering the river.

The rocks are almost entirely of igneous origin and comprise basalts, lavas, and pumice. Some recent lava flows lie around the bases of Mount St. Helens and Mount Adams. The rivers have cut deeply into these formations and in some places ten or more distinct lava flows can be counted. The soil resulting from the disintegration of these rocks is mixed with volcanic ash and is very fertile.

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Trees and brush grow in profusion, and where valley lands have been cleared good crops can be raised.

About one-fourth of the Lewis River drainage basin lies within the Columbia National Forest. Within this area the average stand of timber is over 13,000 feet b. m. per acre. The entire area is essentially densely forested, and although logging operations have been carried on for years the cut-over area forms a relatively small part of the total. The lands contiguous to the lower portion of the river are the only ones that show the effect of these logging operations, and they are rapidly being restocked except where they have been cleared for agriculture. Red and yellow fir are the predominating species and constitute about 50 per cent of the total stand. There are also large quantities of hemlock, Noble fir, and cedar. All through the forests the underbrush is very dense. Wherever the continuous shade of the large trees has been broken by logging or on burned areas the undergrowth is most pronounced. Salal, vine maple, huckleberry, dogwood, syringa, snowberry, wild rose, blackberry, and salmonberry are prevalent species. These, mingled with young seedlings of the conifers and with ferns, vines, and brambles and the decaying and moss-covered trunks of fallen trees, make an almost impenetrable mass.

The Seattle and Portland line of the Northern Pacific Railway crosses Lewis River near its mouth, and a logging branch line runs from Vancouver to Yacolt, near the headwaters of Cedar Creek. The main stream is navigable for small boats as far as Ariel except during the low-water season. A river steamer runs regularly between Portland and Woodland, and a small steamboat runs from Woodland to Ariel, or Runyons Landing, as this place was known before the post-office was established.

A wagon road follows the north bank of the river from Woodland to Petersons and there is a good trail from Petersons to Pine Creek. There is also a wagon road on the south side of the river from Woodland to Cressup's ferry. The drainage area of South Fork is not so mountainous and is much better improved, there being a goodly number of settlers and roads in all directions.

The percentage of farming land in this area is comparatively small. Where timbered lands have been cleared, however, as along the rolling table-lands and broader valley of South Fork and the lower portions of the main river, good crops can be grown. Farther upstream the valley becomes narrower and the suitable farm land is in small benches or narrow strips in the floor of the canyon. All crops common to a mild and moist climate are grown. Fruits of all kinds are found in abundance. Apples, pears, cherries, and small fruits and berries are grown with excellent results. At present, however, the principal industry is lumbering. There are a number of lumber and shingle mills near the mouth of the river, although most of the logs cut are

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transported by water to the mills on Columbia River. At many points along the main stream flumes lead from the high mountains to the river bank. These are used for floating shingle bolts from the hills into the river.

So far as known there are no favorable sites where a large amount of storage could be developed. In the canyon of the main stream there are numerous dam sites where a moderate amount of storage could be developed for the use of a power plant with daily load variations.

Lake Merrill (Pl. IX, *B*) lies on the divide between the headwaters of Cougar Creek and Kalama River. It has no surface outlet, but its waters probably find their way through the lavas that surround it into both these streams. It could doubtless be raised and water could be diverted in either direction, although diversion into Kalama River would be the easier. The formations indicate that the larger portion of the water now flows into Kalama River. The water surface of the lake is less than 1 square mile and the drainage area comprise 6.9 square miles.

So far as could be learned no records of discharge or of gage heights have been kept on any of the streams in this basin. There is a gage at Woodland which is used as a guide for determining the time of running boats, and another one was found at Ariel, but no systematic records of river heights have been kept from either of them.

During the course of the survey, gages were established and discharges during the summer of 1909 were determined at the following points:

Lewis River above Muddy River.
Lewis River above Swift Creek.
Lewis River at Ariel.
Muddy River at the mouth.
Pine Creek at the mouth.
Swift Creek at the mouth.

The last habitation is that of Ole Peterson, who lives 5 miles above Cougar post-office, 2 miles below the mouth of Swift Creek. Mr. Peterson kept daily gage records of the station on Lewis River above Swift Creek and on Swift Creek and made occasional trips to the upper stations. Daily records were also procured at Ariel. In this manner the summer flow for the season is fairly well determined. All stations were discontinued as soon as high water came in the fall except the one on Lewis River above Swift Creek, which is being maintained in cooperation with H. L. Gilbert, civil and hydraulic engineer, of Portland, Oreg.

In addition to the data obtained at these stations, miscellaneous discharge measurements were made of other tributaries and at other points on the main stream, as given in the table following those for the

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regular station. A few gagings were made by H. L. Gilbert in 1907. These are published in Water-Supply Paper 252, page 80, but are repeated here for comparison with the results obtained in 1909:

LEWIS RIVER ABOVE MUDDY RIVER, NEAR COUGAR.

This station was established August 8, 1909, for the purpose of determining discharge during the low-water season only. The gage is a vertical staff on the right bank one-half mile above the mouth of Muddy River. It is fixed near the downstream end of a rocky bluff on the right bank, at the first riffle below this bluff. Measurements were made by wading opposite the gage. No facilities were installed for making measurements at high stages.

Discharge measurements of Lewis River above Muddy River, near Cougar, Wash., in 1909.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
		Feet.	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Sec.-ft.*
August 8	C. W. Harris	147	247	1.72	1.06	[a] 427
August 13	do	88	164	2.62	1.04	[b] 430

[a] Made by wading opposite gage. [b] Made by wading 2 miles above gage.

Daily gage height, in feet, of Lewis River above Muddy River, near Cougar, Wash., for 1909.

[Ole Peterson, observer.]

Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.
1				11				21			
2				12				22	1.0		
3				13	1.04			23			
4		0.92		14				24			
5				15			0.80	25			
6				16				26			
7				17				27			
8	1.06			18				28	.95		
9				19			.90	29			
10				20				30			
								31			

Daily discharge, in second-feet, of Lewis River above Muddy River, near Cougar, Wash., for 1909.

Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.
1	500	295	240	11	440	200	160	21	350	350	500
2	500	295	200	12	425	200	160	22	350	240	350
3	440	262	160	13	410	200	160	23	295	240	425
4	440	262	200	14	410	200	160	24	295	200	350
5	440	295	240	15	425	200	160	25	295	200	240
6	440	240	295	16	410	160	160	26	295	160	240
7	440	240	295	17	350	160	160	27	295	160	200
8	440	240	240	18	350	160	240	28	295	160	295
9	425	240	240	19	350	295	240	29	295	160	425
10	440	200	200	20	350	350	350	30	295	200	425
								31	295		595

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Monthly discharge of Lewis River above Muddy River, near Cougar, Wash., for 1909.

[Drainage area, 250 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Mean per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
August	500	295	380	1.52	1.75	23,400	B.
September	350	160	225	.90	1.00	13,400	B.
October	595	160	265	1.06	1.22	16,300	B.
The period	500	160	290	1.16	3.97	53,100	

LEWIS RIVER AT PETERSON'S, NEAR COUGAR.

This station was established July 27, 1909. It is located 1,000 feet above the mouth of Swift Creek, at the first riffle below a large outcrop of rock on the right bank. The gage is a vertical staff graduated to feet and tenths in two sections, the first 12 feet being attached to a point of the rock above mentioned. Measurements are made by use of a meter running on a small cable and operated from the bank. The river is crossed by means of a raft.

This station is intended as a permanent one, although facilities for making measurements at high stages have not yet been installed. It is maintained in cooperation with H. L. Gilbert, of Portland, Oreg.

Discharge measurements of Lewis River at Peterson's, near Cougar, Wash., for 1909.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
		Feet.	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Sec.-ft.*
July 27	C. W. Harris	125	333	3.75	3.45	1,250
August 19	do	108	254	3.06	2.95	776

Daily gage height, in feet, of Lewis River at Peterson's, near Cougar, Wash., for 1909.

[Ole Peterson, observer.]

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1		3.32	2.73	2.75	3.75	9.60	16		2.95	2.62	2.55	4.30	4.90
2		3.28	2.73	2.70	8.20	7.10	17		2.95	2.60	2.52	4.50	4.80
3		3.25	2.80	2.70	9.60	6.20	18		2.95	2.53	2.50	7.50	4.60
4		3.20	2.80	2.65	7.40	6.00	19		2.95	2.60	2.80	11.40	4.40
5		3.15	2.80	2.65	6.30	5.60	20		2.95	2.95	3.30	9.50	4.30
6		3.10	2.75	2.82	6.30	5.10	21		2.95	2.83	3.50	8.40	4.20
7		3.10	2.70	2.80	5.30	4.10	22		2.95	2.72	3.10	14.60	4.00
8		3.05	2.70	2.70	5.90	4.70	23		2.85	2.70	3.15	14.10	3.95
9		3.03	2.63	2.65	5.90	4.50	24		2.80	2.65	3.00	12.00	3.90
10		3.05	2.63	2.62	5.95	4.50	25		2.82	2.62	2.90	8.90	3.85
11		3.02	2.65	2.60	5.70	4.60	26		2.75	2.62	2.90	7.20	3.80
12		3.00	2.62	2.53	5.30	6.10	27	3.50	2.75	2.60	2.85	6.80	3.70
13		2.95	2.62	2.60	5.00	5.80	28	3.45	2.75	2.60	2.90	7.00	3.70
14		2.92	2.60	2.52	4.70	5.60	29	3.42	2.75	2.63	3.10	12.75	3.70
15		3.00	2.60	2.55	4.50	5.20	30	3.40	2.75	2.65	3.05	11.40	3.75
							31	3.45	2.80		3.40		3.80

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Daily discharge, in second-feet, of Lewis River at Peterson's, near Cougar, Wash., for 1909.

Day.	July	Aug.	Sept.	Oct.	Day.	July.	Aug.	Sept.	Oct.
1		1,110	633	645	16		778	571	535
2		1,070	633	615	17		778	560	520
3		1,040	675	615	18		778	525	510
4		990	675	588	19		778	560	575
5		945	675	588	20		778	778	1,090
6		900	645	688	21		778	694	1,320
7		900	615	675	22		778	627	900
8		858	615	615	23		708	615	945
9		840	576	588	24		675	588	815
10		858	576	571	25		688	571	740
11		832	588	560	26		645	571	740
12		815	571	525	27	1,320	645	560	708
13		778	571	560	28	1,255	645	560	740
14		755	560	520	29	1,220	645	576	900
15		815	560	535	30	1,200	645	588	858
					31	1,255	675	.....	1,200

Monthly discharge of Lewis River at Peterson's, near Cougar, Wash., for 1909.

[Drainage area, 474 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Mean per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
August	1,110	645	804	1.70	1.96	49,400	A.
September	778	560	604	1.28	1.43	35,900	A.
October	1,320	510	712	1.50	1.73	43,800	A.
The period	1,320	510	707	1.49	5.12	129,100	

LEWIS RIVER AT ARIEL.

This station was established July 7, 1909. It is located opposite Ariel post-office, one-fourth mile above the mouth of George Creek. It was intended as a temporary station only, and no facilities were installed for making measurements at high stages. The gage is a vertical staff fixed to an alder stump on the right bank near the post-office and store. Measurements were made from a boat held in place by a small cable spanning the stream. Conditions at the station are not favorable for good results. The stream is used principally for floating logs. These logs lodging on the riffle in the vicinity of the station cause variable backwater conditions for which it is impossible to make correction.

Discharge measurements of Lewis River at Ariel, Wash., for 1909.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
		Feet.	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Sec.-ft.*
July 8	C. W. Harris	316	1,080	3.15	3.07	3,410
August 23	do	262	708	1.71	1.75	1,210

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Daily gage height, in feet, of Lewis River at Ariel, Wash., for 1909.

[C. R. Keiger, observer.]

Day.	July.	Aug.	Sept.	Oct.	Nov.	Day.	July.	Aug.	Sept.	Oct.	Nov.
1	.....	2.20	1.60	1.98	3.66	16	2.72	1.87	1.56	1.55	4.04
2	.....	2.15	1.60	1.68	9.65	17	2.6	1.83	1.55	1.51	4.55
3	.....	2.15	1.66	1.60	10.30	18	2.54	1.78	1.54	1.50	5.85
4	.....	2.12	1.66	1.66	7.18	19	2.41	1.76	1.53	1.65	9.75
5	.....	2.10	1.69	1.76	5.55	20	2.32	1.74	1.88	2.23	9.30
6	.....	2.05	1.66	1.68	4.70	21	2.45	1.72	2.06	2.88	8.10
7	3.23	2.02	1.64	1.58	5.30	22	2.45	1.74	1.65	2.85	9.26
8	3.02	2.00	1.65	1.56	5.46	23	2.48	1.72	1.62	2.41	10.85
9	2.92	2.00	1.64	1.52	5.34	24	2.50	1.80	1.52	2.22	8.60
10	2.9	1.96	1.60	1.57	5.68	25	2.70	1.80	1.58	2.18	7.57
11	3.32	1.92	1.61	1.60	5.36	26	2.65	1.80	1.55	2.10	7.50
12	3.22	1.90	1.60	1.60	4.72	27	2.6	1.82	1.56	2.00	6.85
13	2.98	1.90	1.60	1.60	4.36	28	2.42	1.58	1.54	2.12	7.25
14	2.82	1.88	1.60	1.60	4.19	29	2.34	1.68	1.70	2.38	9.25
15	2.78	1.90	1.58	1.57	3.71	30	2.3	1.65	2.06	2.46	10.90
						31	2.25	1.64	.....	2.90	.....

Daily discharge, in second-feet, of Lewis River at Ariel, Wash., for 1909.

Day.	July.	Aug.	Sept.	Oct.	Day.	July.	Aug.	Sept.	Oct.
1	.....	1,870	1,050	1,530	16	2,750	1,380	1,010	1,000
2	.....	1,790	1,050	1,150	17	2,540	1,330	1,000	950
3	.....	1,790	1,120	1,050	18	2,440	1,270	980	940
4	.....	1,740	1,120	1,120	19	2,220	1,240	970	1,110
5	.....	1,710	1,160	1,240	20	2,060	1,220	1,390	1,920
6	.....	1,640	1,120	1,150	21	2,280	1,190	1,650	3,030
7	3,690	1,590	1,100	1,030	22	2,280	1,220	1,110	2,980
8	3,290	1,560	1,110	1,010	23	2,340	1,190	1,070	2,220
9	3,110	1,560	1,100	960	24	2,370	1,290	960	1,900
10	3,070	1,500	1,050	1,120	25	2,710	1,290	1,030	1,840
11	3,870	1,450	1,060	1,050	26	2,620	1,290	1,000	1,710
12	3,670	1,420	1,050	1,050	27	2,540	1,320	1,010	1,560
13	3,210	1,420	1,050	1,050	28	2,230	1,030	980	1,740
14	2,930	1,390	1,050	1,050	29	2,100	1,150	1,170	2,170
15	2,850	1,420	1,030	1,020	30	2,030	1,110	1,650	2,300
					31	1,950	1,100	.....	3,070

Monthly discharge of Lewis River at Ariel, Wash., for 1909.

[Drainage area, 728 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Mean per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
August	1,870	1,030	1,400	1.52	1.75	86,100	B.
September	1,650	960	1,110	1.92	2.21	66,000	B.
October	3,070	960	1,510	2.07	2.39	92,800	B.
The period	3,070	960	1,340	1.84	6.35	245,000	

MUDDY RIVER AT MOUTH, NEAR COUGAR.

This station was established August 6, 1909. The gage is a vertical staff located one-half mile above the mouth of the river on the first riffle below a rocky gorge. The station was established for temporary purposes only, to determine the low-water flow for 1909, and no facilities were installed for making measurements at high

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stages. Measurements were made with a meter suspended from a small cable spanning the stream and operated from the river bank. The following measurement was made by C. W. Harris, August 6, 1909:

Width, 87 feet; area of section, 149 square feet; mean velocity, 2.13 feet per second; gage height, 0.80 foot; discharge, 317 second-feet.

Gage height, in feet, of Muddy River at mouth, near Cougar, Wash., for 1909.

[Ole Peterson, observer.]

Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.
1				11				21			
2				12				22	0.75		
3		0.60		13				23			
4				14	0.70			24			
5				15			0.35	25			
6	0.80			16				26			
7				17				27			
8	.80			18				28			
9	.78			19			.60	29			
10				20				30			
								31			

Daily discharge, in second-feet, of Muddy River at mouth, near Cougar, Wash., for 1909.

Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.
1	315	220	185	11	290	185	155	21	290	142	400
2	315	220	185	12	265	185	155	22	290	142	370
3	315	220	170	13	265	185	156	23	290	155	370
4	315	242	170	14	265	170	142	24	242	155	370
5	315	242	185	15	265	170	142	25	220	155	342
6	315	220	202	16	265	170	142	26	220	155	315
7	315	202	185	17	265	170	142	27	220	170	290
8	315	202	170	18	265	155	170	28	220	170	290
9	305	185	170	19	265	155	220	29	220	170	342
10	290	185	170	20	290	155	315	30	220	185	315
								31	242		400

Monthly discharge of Muddy River at mouth, near Cougar, Wash., for 1909.

[Drainage area, 121 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Mean per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
August	315	220	274	2.26	2.61	16,800	B.
September	242	142	182	1.50	1.67	10,800	B.
October	400	142	236	1.95	2.25	14,500	B.
The period	400	142	231	1.90	6.53	42,100	

PINE CREEK AT MOUTH, NEAR COUGAR.

This station was established August 4, 1909. The gage is a vertical staff on the left bank of the stream at the old camp grounds, about one-fourth mile above the mouth of the stream, near the quarter corner between secs. 23 and 24, T. 7 N., R. 6 E.

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The station was established to determine low-water conditions during the summer season of 1909, and no permanent equipment was installed for making measurements at high stages. Measurements were made with a meter suspended from a light cable spanning the stream and operated from the bank.

A measurement was made by C. W. Harris, August 4, 1909, as follows:

Width, 32 feet; area, 53 square feet; mean velocity, 2.68 feet per second; gage height, 1.00 feet; discharge, 142 second-feet.

Gage height, in feet, of Pine Creek at mouth, near Cougar, Wash., for 1909.

[Ole Peterson, observer.]

Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.
1				11				21			
2				12				22			
3				13			0.95	23			
4	1.00			14				24			
5				15				25			
6				16	0.97			26			
7				17				27			
8				18				28			
9				19			1.00	29			
10				20				30			
								31			

Daily discharge, in second-feet, of Pine Creek at mouth, near Cougar, Wash., for 1909.

Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.
1	142	142	142	11	142	136	136	21	138	155	155
2	142	142	142	12	142	136	136	22	138	149	149
3	142	142	142	13	142	136	136	23	138	149	142
4	142	142	142	14	142	136	136	24	138	142	142
5	142	142	142	15	142	136	136	25	138	142	142
6	142	136	136	16	138	136	136	26	138	142	142
7	142	136	136	17	138	136	136	27	138	136	149
8	142	136	136	18	138	136	136	28	138	136	149
9	142	136	136	19	138	142	142	29	138	136	149
10	142	136	136	20	138	149	149	30	138	136	149
								31	138		149

Monthly discharge of Pine Creek at mouth, near Cougar, Wash., for 1909.

[Drainage area, 21 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Mean per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
August	142	138	140	6.67	7.69	8,610	B.
September	155	136	140	6.67	7.44	8,330	B.
October	155	136	141	6.71	7.74	8,670	B.
The period	155	136	140	6.68	22.87	25,600	

SWIFT CREEK AT MOUTH, NEAR COUGAR.

This station was established July 27, 1909, It is located 2 miles from Peterson's ranch, one-fourth mile above the mouth of the

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stream, near the point where the north line of sec. 28, T. 7 N., R. 5 E. crosses Swift Creek. The gage is a vertical staff fixed to the right bank. Measurements are made from a foot log or by wading near the gage. As the station was established only to determine low-water conditions during the summer season of 1909, no equipment was installed for making measurements at high stages.

A measurement was made July 27, 1909, by C. W. Harris, as follows:

Width, 49 feet; area, 78 square feet; mean velocity, 2.30 feet per second; gage height, 2.20 feet; discharge, 179 second-feet.

Gage height, in feet, of Swift Creek at mouth, near Cougar, Wash., for 1909.

[Ole Peterson, observer.]

Day.	July	Aug.	Sept.	Oct.	Day.	July.	Aug.	Sept.	Oct.
1					16		2.1		
1					17				
3			2.1		18				
4			2.1	2.1	19		2.15		2.15
5		2.2	2.1		20				
6			2.1	2.2	21				
7			2.1	2.2	22				
8			2.1	2.15	23				
9					24		2.1		
10				2.1	25				
11					26				2.2
12		2.15		2.05	27	2.2			
13					28	2.2			
14		2.1			29				
15		2.1			30	2.2			
					31				

Daily discharge, in second-feet, of Swift Creek at mouth, near Cougar, Wash., for 1909.

Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.	Day.	Aug.	Sept.	Oct.
1	179	167	167	11	179	167	167	21	173	167	173
2	179	167	167	12	173	167	162	22	173	167	173
3	169	167	167	13	173	167	162	23	167	167	173
4	179	167	167	14	167	167	162	24	167	167	179
5	179	167	173	15	167	167	167	25	167	167	179
6	179	167	179	16	167	167	167	26	167	167	179
7	179	167	179	17	167	167	167	27	167	167	179
8	179	167	173	18	173	167	173	28	167	167	179
9	179	167	167	19	173	167	173	29	167	167	179
10	179	167	167	20	173	167	173	30	167	167	179
								31	167	.....	179

Monthly discharge of Swift Creek at mouth, near Cougar, Wash., for 1909.

[Drainage area, 26 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Mean per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
August	179	167	173	6.65	7.67	10,600	A.
September	167	167	167	6.42	7.16	9,940	A.
October	169	167	172	6.61	7.62	10,600	A.
The period	179	167	171	6.56	22.45	31,140	

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MISCELLANEOUS MEASUREMENTS.

The following miscellaneous discharge measurements have been made in the basin of Lewis River:

Miscellaneous discharge measurements in Lewis River basin.

[By C. W. Harris and H. L. Gilbert.]

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
			Feet.	*Sq. feet.*	*Ft. per sec.*	*Sec.-feet.*
Aug. 12, 1909	Lewis River[a]	Upper falls	143	96	2.53	243
Aug. 13, 1907	do.[b]	Above Muddy River				404
Do.	Muddy River	Mouth				220
July 21, 1909	Cougar Creek[c]	Cougar post-office	32	39	2.70	105
Do.	Siouxon Creek	Yale post-office	33	49	.93	46
July 10, 1907	Canyon Creek	Mouth, near Yale				71
July 7, 1907	Lewis River	Cressup's ferry				1,510
Sept. 21, 1907	do.	do.				1,350

[a] Made below first falls, 15 miles above mouth of Muddy River; water surface marked by notch cut in cedar log buried in bed on left bank at foot of falls.
[b] Made 300 feet above mouth of Muddy River. Water surface 11.7 feet below reference point on 24-inch fir on right bank.
[c] Made from foot log back of Schroder's house. Gage installed this date read 0.52.

AVERAGE MINIMUM DISCHARGE.

From the foregoing data the following tables have been compiled. The first one gives the mean discharge for the lowest week during 1909 at all gaging stations. The second table gives the discharges for these stations combined to represent the upper extremities of sections chosen for computing water power. Those obtained by measurement during 1909 have been increased 20 per cent to represent the average minimum discharge, as explained on page 31. From these data and the miscellaneous measurements the average minimum discharges for other points on the stream have been estimated.

It will be noticed that the minimum discharges per square mile at the gaging stations show no degree of consistency whatever. This has been frequently observed on other river systems where continuous and reliable records have been kept. It results from the fact that the topographic drainage area is not always the effective drainage area. For instance, Pine Creek flows through immense lava beds that extend into the Muddy River drainage basin, and it is conceivable that portions of the Muddy drainage area are connected through underground channels with the Pine Creek drainage area. In a country of lava flows the topographic drainage area can never be even an approximate indication of the discharge. The areas of Swift and Pine creeks and Muddy River consist largely of lava flows. Swift Creek and Muddy River receive glacial water from Mount St. Helens, but Pine Creek does not. Under such conditions a consistency in discharges per square mile of topographic drainage area would be most surprising.

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Mean discharge for lowest week at gaging stations in Lewis River drainage basin, 1909.

Station.	Drainage area.	Week ending—	Discharge.	
			Second-feet.	Second-feet per square mile.
	Sq. miles.			
Lewis River above Muddy River	250	October 17	160	0.64
Lewis River at Peterson's	474	....do	530	1.12
Lewis River at Ariel	728	October 18	1,090	1.50
Muddy River at mouth	121	October 17	148	.12
Pine Creek at mouth	21	October 18	136	6.50
Swift Creek at mouth	26	October 15	164	6.30

Average minimum discharge for Lewis River drainage basin.

Locality.	Drainage area.	Date.	Measured discharge.	Adjusted for average minimum.
	Sq. miles.		*Sec.-ft.*	*Sec.-ft.*
North Fork of Lewis River:				
Upper Falls	114	Aug. 12, 1909 [a]	243	120
Below Muddy River	371	Oct. 17, 1909 [b]	308	367
Below Pine Creek	392	.....do. [b]	444	533
Below Swift Creek	500	.....do. [b]	694	832
Below Cougar Creek	552			1,090
Cressup's ferry	665	Sept. 21, 1907 [a]	1,350	1,210
Ariel	728	Oct. 18, 1909 [b]	1,090	1,310
Muddy River:				
Below Clearwater Creek	28			130
Below Clear Creek	114	Oct. 17, 1909 [b]	148	177
Pine Creek, head of survey	20	Oct. 18, 1909 [b]	136	163
Swift Creek, head of survey	24	Oct. 15, 1909 [b]	164	197
Cougar Creek, head of survey	4	July 21, 1909 [a]	105	30

[a] Date of miscellaneous gaging used as a guide.
[b] Date of ending of week for which measured discharge was lowest.

WATER POWERS.

Lewis River has a fairly well maintained flow during the summer season. This flow is largely supplied from the glaciers on Mount Adams and Mount St. Helens (Pl. XII). The grade of the main stream, however, is not exceptionally steep until the ascent of the main range is begun. From Ariel to the falls, 14 miles above the mouth of Muddy River, the stream falls 1,495 feet in 51.4 miles, an average of 29 feet to the mile. In the upper 14 miles of this distance the average fall is 39.5 feet to the mile; in the last 7 miles the average fall is only 11.3 feet to the mile. Muddy River was surveyed for 9 miles above its mouth, and an average fall of 44.4 feet to the mile was found. Pine Creek drops 233 feet in the last 1.6 miles, an average of 146 feet to the mile. Swift Creek has an average fall at its mouth of 172 feet to the mile, and Cougar Creek 125 feet to the mile.

Many favorable sites for dams are found along the main stream and tributaries. (See Pl. XIV, *B*.) These occur where the canyons narrow to chasms with vertical jagged walls of solid rock. In many

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A. LOWER FALLS ON LEWIS RIVER 72 MILES ABOVE MOUTH.

B. DAM SITE ON LEWIS RIVER 48 MILES ABOVE MOUTH.

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places bed rock is exposed in the bed of the stream or is lightly covered with gravel and bowlders. Along the canyon sides there are many benches upon which open canal construction would be possible. The more feasible sites are along the upper portions of the river, and it is likely that opportunities for high-head developments will be found beyond the limits of the survey. This portion of the river, however, is best reached from the east side of the range—that is, by way of White Salmon River, Trout Creek, and the Indian Race Tracks. There are no trails along Lewis River above Muddy River. The river canyon is almost impassable in this portion, and no further progress could have been made without adding an unwarranted amount to the expense of the investigation.

Being glacier fed, the river is heavily loaded with glacial silt near the headwaters. This silt, however, gradually settles out, and in the lower reaches the water is comparatively clear. Muddy River, the most pronounced glacial tributary, is supplied from the glaciers on Mount St. Helens. Pine Creek is not a glacial stream, the water being largely supplied from ground storage in the lava beds through which it flows. Swift Creek, on the other hand, is glacial, and the waters are white with silt during warm weather.

In computing the water powers in this drainage area the streams have been considered in sections, the length of each section being governed by an important tributary or an abrupt change in grade or the streams being otherwise divided to keep the sections within a reasonable length. The elevations of the water surface at the extremities of these sections, the total fall, the fall per mile, and the drainage area of each section are given. The discharge at the upper end of the section has been estimated from the data presented in the foregoing tables. In determining this discharge an attempt has been made to give an average minimum in the manner already described. Although this figure forms the most uncertain part of the data, it is believed to be conservative.

The horsepower given is 70 per cent of the theoretical power that is computed from the known fall in the section and the estimated discharge at its upper extremity. Seventy per cent is of course an arbitrary proportion, but it represents very nearly the power on turbine shafts that is actually realized in many plants now in operation.

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Water powers in Lewis River drainage basin.

Point on stream.	Distance above mouth.	Elevation.	District between points.	Fall between points.	Fall per mile.	Drainage area.	Average minimum charge
							Second feet.
Main stream.							
	Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Sq. m.*	
Above upper falls	74.00	1,585				114	120
Below lower falls	72.33	1,435	1.67	150	89.8	114	120
Above mouth of Muddy River	59.92	1,030	12.41	405	32.6	250	
Below mouth of Muddy River	59.92	1,030				371	367
Above mouth of Pine Creek	59.35	1,012	.57	18	31.6	371	
Below mouth of Pine Creek	59.35	1,012				392	533
Above mouth of Swift Creek	47.38	625	11.97	387	32.3	474	
Below mouth of Swift Creek	47.38	625				500	832
Above mouth of Cougar Creek	41.70	430	5.68	195	34.3	540	
Below mouth of Cougar Creek	41.70	430				552	1,090
Cressup's ferry	30.75	175	10.95	255	23.3	665	1,210
Ariel	23.20	90	7.55	85	11.3	728	1,310
Muddy River.							
Below mouth of Clearwater Creek	9.45	1,450				28	130
Below mouth of Clear Creek	4.60	1,205	4.85	245	50.5	114	177
Mouth		1,030	4.60	175	38.0	121	
Pine Creek.							
Head of survey	1.60	1,245				20	163
Mouth		1,012	1.60	233	146	21	
Swift Creek.							
Head of survey	1.37	860				24	197
Mouth		625	1.37	235	172	26	
Cougar Creek.							
Head of survey	1.40	605				4	30
Mouth		430	1.40	175	125	6	

TOUTLE RIVER DRAINAGE BASIN.

DESCRIPTION.

Toutle River, the largest tributary of Cowlitz River, has in Spirit Lake, on the northwestern slope of Mount St flows in a general westerly direction, and empties int River 2 miles above Castle Rock, Wash. The total leng river from the outlet of Spirit Lake to its junction wit River is 54.3 miles, and the total fall in that distance is 3 Plate XV is a map of the Cowlitz River drainage basin, Toutle River drains a part.

The principal tributaries, in their order downstream, Creek, Hoffstadt Creek, and Green River from the north Creek, South Fork, and Outlet Creek from the south.

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The total drainage area is 510 square miles, distributed as follows:

	Square miles.
Spirit Lake outlet	12
Above mouth of Green River	143
Above mouth of South Fork	295
At Tower gaging station	474
Mouth	510
Green River	128
South Fork	134
Outlet Creek	42

The prominent topographic feature of the area is Mount St. Helens (Pl. XII, *B*). The elevation of this peak has not been accurately determined, but is given as between 9,750 and 10,000 feet. The general topography of the region is bold and rugged, somewhat similar to that of the adjoining basin of Lewis River. The area is probably the dissected and eroded remainder of a broad plateau that was modified by distorting uplifts and more or less covered with lava flows.

The country to the north and east of Mount St. Helens is included in the St. Helens mining district, and here the volcanic rocks are absent. The general formation in the mining district is syenite cut by porphyry dikes striking almost northwest and dipping 60° or 70° W. Northwest of the syenite belt the country rock is mostly quartzite, broken and traversed by a series of almost perpendicular veins, whose general strike is northeast and southwest. Many of the veins of the district are of great width and carry sulphide ores, mostly of copper, iron, and lead. They are true fissure veins and are found along the contact between the porphyry dikes and the country rock.[a]

The lands contiguous to the lower portion of the river are high and rolling but not rugged. Upstream these rolling lands are gradually replaced by narrower valleys and bench lands topped by bold peaks with scarred and eroded sides. The river canyons, however, are not so abrupt as those of the other streams considered in this report, but the sides are of more uniform slope with here and there a rocky bluff on one bank or the other. The stream flows on a bed of gravel and cobblestones through almost its entire length, with scattered ledges of partly exposed bed rock dipping steeply into the gravel bed of the river. This indicates that the river canyons at one time were deeper but that they have been filled by water-deposited gravel and talus from the canyon sides.

Only a small portion of this area lies within the Columbia National Forest. The west line of T. 5 N. is the western boundary of this forest, but practically all tracts along the river within it are patented lands.

[a] Ann. Rept. Washington Geol. Survey for 1901, vol. 1, pt. 2.

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The average stand of timber on the area is probably 10,000 feet b. m. per acre except where it has been logged off. The timber from the easily accessible tracts has been partly removed, but the greater portion of the timber in the basin is still in its virgin state. Most of the logged-off areas are being restocked and all is covered with young growth and underbrush except where the lands have been cleared for agriculture.

The species found are those common to the western slope of the Cascade Range. Red or yellow fir constitutes about 50 per cent of the stand, cedar about 10 per cent, hemlock 5 per cent, and white fir 5 per cent, with considerable quantities of Noble fir, mountain hemlock, and Englemann spruce. The rivers are lined with dogwood, alders, and maple, and over all there is a dense undergrowth of vines, brambles, ferns, and deciduous shrubs.

The Seattle and Portland line of the Northern Pacific Railway crosses the river near its mouth, but elsewhere there are no railroads in the area. There is a wagon road from Castle Rock to Spirit Lake and from it roads and trails lead in various directions. A trail follows Green River to the Saint Helens mining district. The lower portion of the drainage area is well provided with wagon roads. Roads lead from Castle Rock to Silver Lake and Sightly and to points on South Fork and the rolling lands between that stream and Cowlitz River.

The first discoveries of metalliferous ores in the mining district were made in 1891 and the district was formed September 22, 1892. At the present time there is considerable activity in this region, and there is every indication that if transportation facilities were provided some valuable mining property would be developed here. The mines and proposed transportation lines to them should afford a good market for water power.

Agriculture plays no small part in this region. All along the river and on the rolling lands nearer the mouth many tracts have been cleared for diversified farming or planted to orchards. The soil is rich and the climate is favorable for fruit raising and other forms of intensive agriculture. Hay and grains are plentiful along the shores of Silver Lake, and garden vegetables, potatoes, and small fruits and berries are raised in abundance wherever the attempt has been made.

Lumbering, however, has been and probably will continue for some years to be the principal industry. Several small shingle and lumber mills are in operation, but the greater portion of the logs are transported to the larger mills on lower Cowlitz and Columbia rivers.

At present there are no developed water powers in the drainage area, but near the outlet of Spirit Lake some power rights have reached

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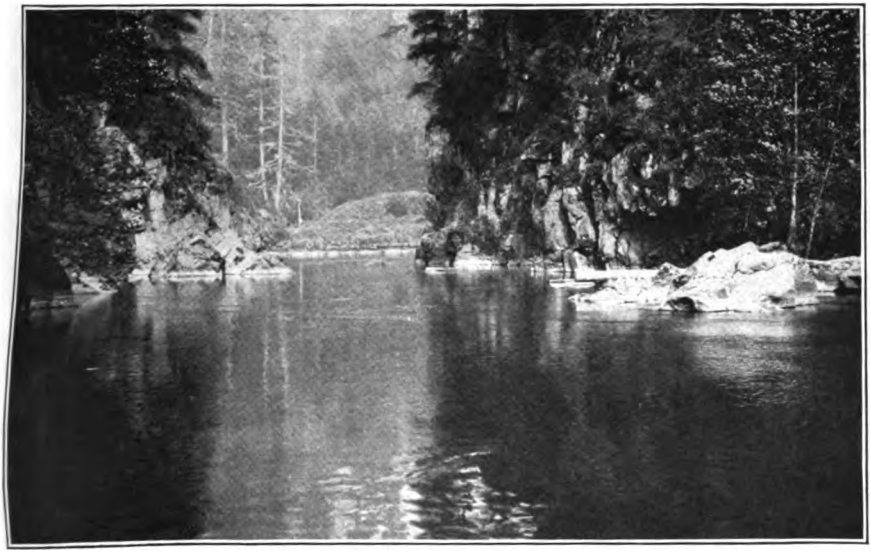

A. DAM SITE ON TOUTLE RIVER NEAR MOUTH.

B. DRIFTWOOD ON TOUTLE RIVER NEAR ST. HELENS.

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the point of preliminary construction of crib dams and diverting flumes. (See Pl. XVI, *A*.)

The properties are claimed by adverse interests, so that all work has been stopped by injunction and the respective rights are in litigation.

Spirit Lake, at the head of the main stream, has a total drainage area of 12 square miles and a normal surface area of 2.2 square miles. About 80,000 acre-feet could be developed by raising the water surface 50 feet. This is equivalent to a uniform flow of 200 second-feet for 200 days. There is no doubt that this reservoir would be filled each winter season. Silver Lake (or Toutle Lake, as it is sometimes called), in the lower portion of the area, has a drainage area of 42 square miles and a surface area of 5.1 square miles. Its water surface could not be raised very much, but it is probable that 50,000 acre-feet could be stored. The run-off from the drainage area, however, is relatively small, and Outlet Creek, which joins it to the trunk stream, is usually dry in summer.

Toutle River is a glacial stream. The summer flow is largely supplied by the glaciers on the northern slope of Mount St. Helens. The waters from these glaciers do not flow into Spirit Lake, but reach the main stream through three tributaries from the south. Some water from the glaciers on the west side of the mountain flows into South Fork, but the contribution to that stream from this source is small. Green River, as its name implies, is not glacier fed, but the waters are supplied from surface drainage and ground storage during the summer. Its headwaters reach into the high spurs of the main range and it doubtless draws from snow banks that remain well into the summer.

During the course of the surveys discharge data were obtained at critical points. A temporary station was established on Toutle River at St. Helens and a permanent station near Tower, below all important tributaries. In addition to these data, discharge measurements were made at several points, the results of which are given as miscellaneous measurements.

TOUTLE RIVER AT ST. HELENS.

This station was established September 11, 1909. It is located at the county bridge across Toutle River in the SE. ¼ sec. 15, T. 10 N., R. 2 E., above the mouth of Alder Creek. The gage is a vertical staff 10 feet long, graduated to feet and tenths, and fixed to the downstream end of the left abutment of the bridge. Discharge measurements are made from the highway bridge. The station was established for temporary purposes only, and observations were suspended at the close of the summer season.

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Discharge measurements of Toutle River at St. Helens, Wash., for 1909.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
		Feet.	*Sq. ft.*	*Ft. per sec.*	*Feet.*	*Sec. ft.*
September 11	C. W. Harris	81	133	1.89	1.07	252
September 21	do	81	140	2.25	1.19	313

Daily gage height, in feet, of Toutle River at St. Helens, Wash., for 1909.

[Iner Fouske, observer.]

Day.	Sept.	Oct.	Day.	Sept.	Oct.	Day.	Sept.	Oct.
1		1.10	11	1.07		21	1.09	
2		1.06	12	1.05		22	1.05	
3		1.04	13	1.02		23	1.03	
4		1.03	14	1.01		24	1.05	
5			15	1.01		25	1.07	
6			16	1.02		26	1.03	
7			17	1.04		27	1.01	
8			18	1.02		28	1.03	
9			19	1.02		29	1.10	
10			20	1.10		30	1.14	

Daily discharge, in second-feet, of Toutle River at St. Helens, Wash., for 1909.

Day.	Sept.	Oct.	Day.	Sept.	Oct.	Day.	Sept.	Oct.
1		270	11	257		21	266	
2		253	12	248		22	248	
3		244	13	235		23	240	
4		240	14	231		24	248	
5			15	231		25	257	
6			16	235		26	240	
7			17	244		27	231	
8			18	235		28	240	
9			19	235		29	270	
10			20	270		30	290	

TOUTLE RIVER NEAR TOWER.

This station was established September 4, 1909. The gage is a vertical staff located at the downstream end of a rocky bluff on the right bank one-fourth mile above G. K. Walker's house, near the quarter corner between secs. 12 and 13, T. 10 N., R. 1 E., 2½ miles below the mouth of South Fork of Toutle River and Outlet Creek.

It is intended that this station shall be permanent, but as yet no facilities have been installed for making measurements at high stages. Measurements during the low-water period can be made by wading, and in this manner estimates for the present season have been made.

A measurement was made by C. W. Harris, September 4, as follows:

Width, 124 feet; area, 234 square feet; mean velocity, 1.78 feet per second; gage height, 1.24 feet; discharge, 416 second-feet.

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Daily gage height, in feet, of Toutle River near Tower, Wash., for 1909.

[G. K. Walker, observer.]

Day.	Sept.	Oct.	Nov.	Dec.	Day.	Sept.	Oct.	Nov.	Dec.
1	.....	1.45	2.49	5.82	16	1.19	1.21	2.75	3.78
2	.....	1.35	6.10	4.95	17	1.19	1.20	2.55	3.53
3	.....	1.30	7.60	4.42	18	1.18	1.19	3.30	3.32
4	1.24	1.25	5.60	4.00	19	1.15	1.22	5.40	3.18
5	1.25	1.22	4.50	3.72	20	1.15	1.80	6.50	3.04
6	1.21	1.44	4.00	3.45	21	1.85	2.38	5.40	2.95
7	1.21	1.67	3.52	3.30	22	1.42	2.30	7.52	2.80
8	1.20	1.45	3.90	3.25	23	1.30	1.89	8.00	2.70
9	1.18	1.40	4.00	3.20	24	1.25	1.97	8.85	2.64
10	1.20	1.38	4.10	3.17	25	1.26	1.84	6.50	2.60
11	1.35	1.36	3.70	3.16	26	1.30	1.73	5.34	2.55
12	1.24	1.30	3.40	5.34	27	1.21	1.65	4.65	2.50
13	1.21	1.29	3.32	5.30	28	1.20	1.59	5.00	2.45
14	1.21	1.29	3.09	4.56	29	1.34	1.75	6.25	2.40
15	1.20	1.25	2.89	4.12	30	1.67	1.81	7.60	2.33
					31	.....	1.90	.....	2.90

Daily discharge, in second-feet, of Toutle River near Tower, Wash., for 1909.

Day.	Sept.	Oct.	Day.	Sept.	Oct.	Day.	Sept.	Oct.
1	.....	468	11	442	445	21	574	.....
2	.....	442	12	415	430	22	460	.....
3	.....	430	13	408	428	23	430	585
4	415	418	14	408	428	24	418	.....
5	418	410	15	405	418	25	420	572
6	408	465	16	403	408	26	430	542
7	408	526	17	403	405	27	408	520
8	405	468	18	400	403	28	405	504
9	400	455	19	394	410	29	440	548
10	405	450	20	394	561	30	526	564
						31	.....	588

MISCELLANEOUS MEASUREMENTS.

The following miscellaneous discharge measurements were made in the basin of Toutle River:

Miscellaneous discharge measurements in Toutle River basin.

[By C. W. Harris and H. L. Gilbert.]

Date.	Stream.	Locality.	Width.	Area of section.	Mean velocity.	Discharge.
			Feet.	*Sq. ft.*	*Ft. per sec.*	*Sec.-ft.*
May 27, 1907	Toutle River	Outlet of Spirit Lake	.....	.....	.....	206
Sept. 18, 1909	.....do[a]	.....do	39	21	1.45	30
Sept. 10, 1909	Green River[b]	Lithow	67	68	.82	56
May 24, 1907	South Fork of Toutle River	Toutle	.....	.....	.....	336
Sept. 7, 1909	.....do	.....do.[c]	68	71	1.25	87

[a] Made at spillway of upper dam. Water surface 7.76 feet below spike in root of 18-inch white fir on right bank 20 feet above dam.

[b] Made by wading 300 feet below highway bridge. Water surface 4.62 feet below 10-penny nail in lower board of left abutment of bridge, upstream end.

[c] Water surface 5.49 feet below lowest rivet of upper longitudinal seam on northwest side of northwest tube of middle pier of county bridge.

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AVERAGE MINIMUM DISCHARGE.

From the foregoing data the following table has been prepared, giving the average minimum discharge at the upper extremity of each section used in computing water powers. The mean discharge for the lowest week as measured at tributaries has been increased 20 per cent, as explained on page 31.

The streams are supplied partly by glacial waters, but the greater portion of the summer flow comes from surface drainage and ground storage. The entire drainage area is more or less effective in producing run-off, and in this respect the stream presents a strong contrast to Lewis River, whose drainage area joins that of Toutle River on the south. The average minimum discharges per square mile (given in power table) are seen to be fairly consistent among themselves. The value for Green River is less than those for the main stream and for South Fork, as would be expected, since it does not draw from the glaciers on Mount St. Helens.

Average minimum discharge in Toutle River drainage basin.

Location.	Drainage area.	Date.	Measured discharge.	Discharge adjusted to average minimum.
Main stream.	*Sq. miles.*	1909.	*Sec.-ft.*	*Sec.-ft.*
Outlet Spirit Lake	12	Sept. 18[a]	30	36
Above Cold Creek	33			92
East line sec. 12, T. N., 9 R 3 E	74			185
St. Helens gaging station	120	Sept. 19[b]	235	282
Below Green River	271	do.[b]	290	348
Below South Fork	420	do.[b]	390	469
Tower gaging station	474	Sept. 20[b]	401	481
North line sec. 21, T. 10 N., R. 1 W	487			490
Green River.				
Lithow bridge	127	Sept. 10[b]	56	64
South Fork.				
Head of survey	122	Sept. 7[b]	87	100

[a] Date of miscellaneous measurement used as a guide.
[b] Date of ending of week for which mean discharge was the lowest.

WATER POWERS.

Toutle River has an average fall, in the 54.3 miles from Spirit Lake to its mouth, of 58.1 feet to the mile. The fall in the upper 10 miles averages 137 feet and in the lower 10 miles 19 feet to the mile. Green River at the mouth has an average fall of 20.8 feet to the mile, but the fall increases rapidly as the stream is ascended. South Fork at its mouth has an average fall of 19.2 feet to the mile, but the grade does not increase greatly until near the spurs of Mount St. Helens.

Although the stream in general flows on a gravel bed, there are many favorable localities for diversion of the water into open canals

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or pressure pipes. The sides of the canyon and the benches along the river afford opportunities for canal construction. The main stream therefore has been divided into sections. The elevations of the water surface at the extremities of these sections, the total fall, the fall per mile, and the drainage area of each section considered are given below. The discharge at the upper end of the section has been estimated from the data already presented. In determining this discharge an attempt has been made to give an average minimum in the manner described on page 31. This figure is the most uncertain part of the data, but it is believed to be conservative.

The horsepower given is 70 per cent of the theoretical power that is computed from the known fall in the section and the estimated discharge at its upper extremity. Seventy per cent is, of course, an arbitrary proportion, but it represents very nearly the power on turbine shafts that is actually realized in many plants in operation under full load.

Water powers in Toutle River drainage basin.

Point on stream.	Distance above mouth.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Drainage area.	Average minimum discharge.		Available horsepower (70 per cent of theoretical).
							Second-feet.	Second-feet per square mile.	
Main stream.	*Miles.*	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Sq. mi.*			
Spirit Lake outlet	54.30	3,204	.....	.....	.....	12	36	3.00	.....
Above mouth of Cold Creek	47.62	2,140	6.68	1,064	159	33	92	2.80	3,040
East line T. 9 N., R. 3 E.	42.75	1,620	4.87	520	107	74	185	2.50	3,800
St. Helens bridge	31.80	885	10.95	735	67.1	120	282	2.35	10,800
Above mouth of Green River	27.55	720	4.25	165	38.8	143	.....	.....	3,700
Below mouth of Green River	27.55	720	.....	.....	.....	271	348	1.28	.....
Above mouth of South Fork	16.45	420	11.10	300	27.0	295	.....	.....	8,300
Below mouth of South Fork	16.45	420	.....	.....	.....	429	469	1.09	.....
Castle Rock gaging station	13.10	305	3.35	115	34.4	474	481	1.01	4,300
North line sec. 21, T. 10 N., R. 1 W.	7.60	160	5.70	145	25.5	487	490	1.01	5,500
Mouth	.....	51	7.60	109	14.2	510	.....	.....	4,200
Green River.									
Lithow Bridge	1.20	745	.....	.....	.....	127	64	.50	.....
Mouth	.....	720	1.20	25	20.8	128	.....	.....	120
South Fork.									
Head of survey	1.30	445	.....	.....	.....	122	100	.82	.....
Mouth	.....	420	1.30	25	19.2	134	.....	.....	200
									44,000

RECORDS OF PRECIPITATION.

In order to present data for more extensive study of the effect of rainfall on stream flow, all available records of precipitation for the territory treated in this report have been compiled from published reports of the United States Weather Bureau and are pre-

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sented in the following table. So few stations have been maintained within the area itself that the records from outlying stations are also given:

Rainfall stations in and near area considered.

Station.	County and State.	Latitude.	Longitude.	Elevation.	Length of record.
		° ′	° ′	*Feet.*	*Years.*
Portland	Multnomah, Oreg.	45 32	122 43	32	41
Vancouver	Clarke, Wash.	45 38	122 42	75	32
Cascade Locks	Hood River, Oreg.	45 40	121 56	100	31
Hood River	do.	45 42	121 30	243	26
The Dalles	Wasco, Oreg.	45 36	121 12	112	52
Lyle (Pine Hill)	Klickitat, Wash.	45 30	121 0	600	18
Goldendale	do.	45 49	120 49	1,600	3
Fort Simcoe	Yakima, Wash.	46 29	120 48	1,427	17
Ellensburg	Kittitas, Wash.	47 00	120 32	1,571	21
Yale	Cowlitz, Wash.	45 57	122 19	375	4
Olympia	Thurston, Wash.	47 03	122 54	25	31

Precipitation at rainfall stations in and near area considered.

PORTLAND, OREG.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1858	.....	.....	.....	1.35	1.51	0.13	.....	.....	.....	.....	.....	.....	.....
1859	.....	8.95	7.85	1.44	1.51	.13	0.22	0.87	.....	.....	.....	.....	.....
1870	4.85	4.30	4.30	4.30	1.95	1.95	.20	.20	0.45	0.55	6.05	4.40	33.50
1871	7.60	5.06	9.84	3.64	5.18	.50	.55	.45	1.15	1.19	2.77	7.62	45.55
1872	6.56	12.13	5.28	2.96	.92	1.52	.20	.13	1.26	1.80	4.67	9.47	46.90
1873	8.49	6.58	12.76	2.35	2.18	2.96	1.02	.84	.00	3.86	4.33	5.15	50.52
1874	9.46	4.28	5.15	3.68	2.38	2.68	.19	.83	1.70	.36	10.22	5.24	46.17
1875	4.49	1.99	9.41	2.10	2.87	2.05	.02	.53	.71	6.73	15.77	13.41	60.08
1876	4.80	7.50	9.12	5.34	1.88	2.35	.96	.56	1.09	10.53	10.03	.88	55.04
1877	2.75	7.56	11.31	2.44	2.24	2.05	.54	1.70	3.36	5.03	12.45	6.87	58.30
1878	6.67	12.16	6.23	1.86	2.17	.13	1.10	.50	3.54	3.22	5.61	4.52	47.71
1879	5.28	13.22	11.70	2.19	6.60	2.18	1.75	.97	2.18	4.23	4.56	7.36	62.22
1880	12.27	5.67	4.48	2.92	3.13	1.59	.59	1.31	1.34	1.47	3.17	13.93	51.87
1881	8.57	13.36	2.83	3.51	1.38	2.34	1.16	2.11	2.64	6.60	6.91	6.64	58.05
1882	5.06	10.49	2.53	4.60	1.84	1.91	.95	.07	.91	11.63	7.11	20.14	67.24
1883	13.71	2.34	6.40	7.88	1.67	.08	.10	.19	.67	3.91	8.26	6.34	51.45
1884	3.70	4.88	2.25	3.57	1.34	1.42	1.80	.33	4.25	4.01	3.24	7.52	38.31
1885	4.57	6.72	.63	1.12	4.09	1.77	.24	.00	2.48	1.68	8.52	7.17	39.57
1886	9.33	1.96	5.39	3.16	1.32	.67	.32	.03	1.19	2.87	1.00	11.52	38.76
1887	12.31	2.81	8.00	5.06	4.77	1.44	.03	.58	3.06	1.34	3.43	11.34	54.17
1888	8.50	2.42	2.87	2.06	.68	5.38	1.04	.05	1.13	4.97	4.47	5.19	38.76
1889	4.78	1.07	1.80	2.72	4.02	.51	Tr.	.90	1.61	4.59	3.97	5.79	31.76
1890	11.13	9.85	6.23	1.41	1.08	2.23	.59	.13	.10	2.79	.50	4.34	40.38
1891	3.62	6.26	2.06	4.00	1.83	4.07	.24	.93	2.17	5.04	5.74	11.45	47.41
1892	4.79	2.48	2.82	4.82	1.57	1.41	.70	.17	1.63	2.16	4.34	6.69	33.58
1893	2.12	5.19	3.48	4.89	2.30	.99	.14	Tr.	2.56	5.01	7.74	4.61	39.03
1894	9.65	5.16	7.48	2.57	1.09	2.16	.10	Tr.	1.32	3.56	2.76	3.47	39.32
1895	8.53	1.01	2.84	1.91	3.42	.57	.23	.37	1.16	Tr.	2.93	7.79	30.76
1896	6.52	3.44	2.19	4.09	3.55	1.41	Tr.	1.32	.47	1.76	13.12	6.26	44.13
1897	3.25	5.57	4.00	1.76	.90	1.35	.65	.26	2.79	1.99	11.65	8.84	43.01
1898	3.91	6.51	2.17	2.12	1.78	1.88	.79	.15	2.69	1.58	6.03	4.29	33.90
1899	6.42	4.20	2.30	3.73	3.16	.62	.47	2.50	1.37	3.97	7.56	5.91	42.21
1900	4.58	3.36	4.63	1.30	3.90	1.76	.34	2.04	1.93	3.87	4.50	6.01	38.22
1901	7.80	6.52	4.12	4.05	2.41	1.39	.12	.17	3.57	.75	6.14	4.01	41.05
1902	3.11	8.66	5.79	3.71	2.19	.80	1.76	.44	4.75	1.72	9.94	10.28	50.15
1903	5.43	1.44	4.29	2.25	1.71	2.00	.51	.81	1.13	2.20	10.71	3.14	35.62
1904	5.22	11.08	8.73	2.26	.59	.45	.73	.20	.28	2.29	7.40	7.14	46.37
1905	3.66	1.77	5.03	1.71	2.56	2.12	.12	.19	2.79	4.73	3.01	6.41	34.10
1906	5.72	6.76	2.23	2.02	2.00	3.03	Tr.	.05	2.20	3.43	8.30	7.55	43.29
1907	8.23	3.54	3.86	3.57	1.37	1.84	1.19	1.02	1.73	.93	6.51	9.10	42.89
1908	4.73	2.85	4.39	3.38	4.66	.67	.05	1.34	.23	5.17	3.10	3.80	34.37
1909	9.29	7.03	2.35	.89	1.79	.17	2.26	.65	.95	2.01	12.49	4.47	44.35

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Precipitation at rainfall stations in and near area considered—Continued.

VANCOUVER, WASH.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1849	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.00	.....
1850	6.66	2.60	6.71	0.60	0.40	3.22	8.35	0.00	0.98	2.69	4.90	1.29	38.40
1851	9.55	2.04	4.08	.....	.....	.....	.....	.....	.....	.....	.....	7.93	.....
1852	9.31	4.77	4.26	6.56	3.49	1.77	.....	.....	.....	1.55	7.37	13.37	55.95
1853	9.30	4.21	2.47	1.72	2.33	.90	.30	.39	2.00	3.66	11.57	3.22	42.07
1854	.....	2.83	1.22	2.78	.75	2.41	.00	1.72	.00	2.31	3.19	8.34	32.75
1855	13.29	3.84	3.99	2.04	3.77	2.43	.....	.00	.46	1.41	2.05	10.77	45.43
1856	5.00	3.07	1.01	4.01	4.08	3.26	2.89	.08	2.37	4.81	6.62	15.37	52.57
1857	6.74	4.39	7.30	.37	3.04	2.09	.....	.14	1.87	.96	7.01	12.28	47.57
1858	5.62	6.90	4.20	1.98	2.30	1.82	.00	.71	4.37	3.55	4.25	4.76	40.46
1859	5.77	5.10	9.60	1.90	2.00	.16	.25	1.02	4.19	2.22	4.15	2.40	38.86
1860	5.57	2.77	2.93	1.95	2.92	1.00	1.25	.35	1.52	3.78	6.31	4.12	34.47
1861	4.60	6.32	3.05	3.05	3.40	2.70	.00	.20	.75	2.88	7.70	7.40	42.05
1862	3.47	1.80	5.31	3.10	3.87	3.05	1.43	1.00	.45	1.30	.85	4.87	30.40
1863	8.70	6.46	2.75	3.50	2.45	.90	1.10	.65	1.70	3.61	4.23	6.36	42.41
1864	5.35	1.73	3.94	1.90	.67	1.79	.34	.30	2.81	1.05	5.93	5.67	31.48
1865	2.38	1.32	2.71	.....	.76	.94	.83	.68	.....	.68	6.53	1.55	25.91
1866	.80	.89	4.15	2.11	.....	.....	.....	.....	.08	1.53	2.63	4.69	.....
1867	3.85	3.68	.97	1.98	.90	.79	1.19	.00	1.14	2.45	2.14	16.04	35.13
1868	2.22	1.02	2.89	2.36	1.01	3.78	.55	.....	.....	.....	.....	.....	.....
1891	3.53	4.37	1.84	4.46	1.70	3.42	.38	1.30	2.68	4.52	6.50	9.70	44.40
1892	4.22	2.35	2.49	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1848	.....	.....	.....	.....	2.42	2.01	.85	.18	2.89	1.84	5.48	4.49	.....
1899	6.46	4.39	2.46	3.75	4.00	1.20	.10	3.03	1.83	5.05	9.07	5.86	47.20
1900	4.00	3.90	4.55	2.13	4.40	2.66	.82	.32	1.96	4.25	4.34	7.10	40.43
1901	6.66	6.70	4.71	3.36	2.29	1.89	.18	.18	3.07	1.10	6.74	3.68	40.56
1902	3.86	9.14	4.76	3.14	2.28	.75	1.94	.31	1.92	1.74	10.00	11.13	50.97
1903	5.29	1.84	4.07	2.40	1.71	2.06	.37	.56	1.58	2.26	9.34	2.77	34.25
1904	4.49	9.13	7.69	2.44	1.16	.39	.51	.15	.21	2.23	7.21	6.82	42.43
1905	4.46	1.95	4.05	1.54	3.36	2.40	.24	.18	2.53	4.15	2.97	5.47	33.30
1906	4.90	5.90	2.47	1.63	2.41	3.34	Tr.	.05	2.09	3.25	9.42	6.92	42.38
1907	6.55	4.67	2.67	2.81	1.56	1.80	.99	1.38	2.17	.68	5.77	8.81	39.86
1908	4.20	2.80	3.85	3.05	4.31	.80	.08	1.68	.16	4.40	3.26	4.1	32.77
1909	9.33	6.26	2.10	.87	1.91	.14	2.41	.07	1.41	2.43	12.79	4.52	44.24

CASCADE LOCKS, OREG.

1879	.....	.....	16.48	5.02	7.19	1.18	3.97	1.45	5.02	7.91	11.67	15.43	.....
1880	19.64	9.08	7.50	5.17	5.05	3.40	.55	2.38	1.73	4.73	7.93	15.52	82.68
1881	14.23	24.71	7.26	7.05	2.32	5.31	1.61	1.69	3.83	11.23	9.53	10.14	98.91
1882	10.56	12.75	4.40	7.42	1.93	1.82	2.05	.45	1.15	14.75	6.19	19.06	82.53
1883	22.70	2.87	5.39	10.80	1.90	.30	.00	.00	1.00	7.81	15.21	8.89	76.87
1884	9.27	10.89	3.06	6.22	1.75	1.99	1.08	.00	6.38	10.22	4.80	15.42	71.08
1885	5.45	16.72	1.60	.78	4.60	1.55	.23	.00	7.50	2.89	12.19	12.64	66.15
1886	11.01	6.81	10.00	4.27	3.42	.31	.56	.00	2.93	4.72	3.38	20.94	68.41
1887	29.90	3.85	14.09	8.15	6.68	1.32	.00	.40	4.02	3.98	7.65	20.60	100.64
1888	10.90	3.59	5.74	2.23	.36	6.43	1.72	.15	.97	9.56	9.68	8.65	59.98
1889	4.54	2.79	3.39	5.38	4.34	1.89	.00	1.00	4.95	6.52	6.80	8.46	50.06
1890	14.42	22.28	7.10	2.81	.75	6.54	.48	.39	.02	6.86	1.74	7.57	70.96
1891	9.00	9.69	6.52	5.60	1.94	4.45	1.22	1.84	3.02	8.31	13.25	21.50	81.23
1892	9.89	4.98	4.63	8.79	2.18	.80	1.66	.21	2.44	4.81	13.19	9.95	63.22
1893	2.14	11.46	10.03	13.81	4.70	3.02	.15	.16	7.06	8.00	15.10	13.37	89.60
1894	21.80	10.71	16.52	7.76	2.31	3.73	.42	.00	5.89	11.21	6.93	6.94	94.22
1895	12.71	3.46	7.35	5.34	7.91	.43	1.15	.13	3.88	.20	8.87	19.60	71.03
1896	11.45	11.18	7.68	9.44	7.54	3.02	.00	.65	1.66	3.85	23.65	14.85	94.97
1897	6.20	14.37	11.47	4.04	1.33	2.75	.62	1.43	4.01	3.95	19.24	19.26	88.07
1898	10.63	14.48	5.56	3.13	2.67	1.83	1.65	1.28	6.78	3.36	16.75	8.16	76.28
1899	15.34	13.93	6.85	11.65	4.65	2.41	.08	4.82	2.69	7.04	16.66	11.83	97.95
1900	11.06	9.65	7.15	2.15	4.49	3.33	.26	1.32	3.00	12.84	10.52	10.96	76.73
1901	11.87	15.28	9.54	5.61	2.66	1.95	.13	.19	4.60	1.96	11.32	11.94	76.97
1902	7.80	12.73	11.26	7.56	4.11	1.49	1.51	.27	3.09	2.69	21.01	19.83	93.35
1903	17.28	2.47	3.89	3.84	2.52	4.63	.68	.47	4.50	7.39	16.21	8.36	72.24
1904	12.12	14.94	15.09	3.45	.69	2.08	1.04	.31	.09	3.33	8.66	14.46	76.26
1905	5.66	3.68	8.97	1.49	4.75	1.08	.00	.73	5.43	9.41	5.27	12.19	58.66
1906	7.84	11.54	2.71	2.80	2.84	1.62	.00	.09	4.84	7.93	17.84	13.42	77.98
1907	11.95	9.33	5.77	9.53	1.87	2.19	.84	1.80	3.45	1.62	12.53	18.81	79.69
1908	9.08	5.86	12.39	4.08	4.98	2.22	.17	2.22	.45	7.87	5.57	10.26	65.15
1909	1.72	11.26	5.27	3.03	4.30	.89	1.29	.58	2.34	4.59	26.10	4.25	65.62

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Precipitation at rainfall stations in and near area considered—Continued.

HOOD RIVER, OREG.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1884	3.70	5.90	1.30	3.35	1.10	1.15	0.25	0.10	3.30	3.60	1.70	12.70	33.15
1885	5.40	8.15	.30	.60	1.30	1.30	.00	.00	2.65	1.15	5.00	6.50	32.35
1886	10.65	1.90	4.35	2.10	.80	.15	.05	.00	1.30	2.20	1.15	10.40	35.05
1887	16.80	3.50	4.90	1.40	2.00	.65	.00	.25	1.75	.65	2.90	10.75	45.55
1888	8.15	1.70	2.95	1.10	.20	4.00	.55	.05	.03	4.10	4.10	5.25	32.18
1889	2.90	.65	1.90	1.95	1.25	.25	.02	.23	2.00	2.10	3.75	5.50	22.50
1890	7.60	9.70	3.70	1.20	.40	.85	.20	.10	.00	3.25	.10	3.85	30.95
1891	2.45	6.70	2.80	1.10	1.00	1.20	.35	.05	1.18	2.45	4.55	12.85	36.68
1892	4.45	1.50	1.80	4.02	.75	.54	.27	.12	.90	2.12	5.83	10.94	32.24
1893	3.25	8.03	4.23	5.76	2.58	.58	.33	.00	3.26	9.81	9.56	6.86	54.17
1894	11.72	5.03	12.67	1.68	1.56	1.79	Tr.	.00	2.00	3.93	3.78	4.13	48.29
1895	10.85	1.16	3.68	1.90	3.33	[.25]	.64	.15	2.91	.01	3.82	12.83	.....
1896	7.61	4.53	5.00	3.17	3.78	.54	Tr.	.22	.98	1.81	16.55	7.17	51.36
1897	2.85	7.45	6.78	1.84	.81	.95	.18	.30	1.29	1.24	10.64	12.54	46.87
1898	3.72	5.83	2.10	.95	.86	1.31	.80	.09	2.74	1.15	7.35	4.17	31.07
1899	7.55	5.89	4.04	3.89	2.16	1.66	Tr.	2.01	.68	3.62	7.72	4.96	44.18
1900	[6.40]	[5.80]	1.43	.86	.50	1.00	.00	.29	1.89	4.59	5.46	5.45	.....
1901	7.66	7.81	2.93	2.82	.51	.42	Tr.	.27	3.30	.12	6.29	4.75	36.88
1902	3.81	7.09	3.61	3.34	1.06	.30	.38	.01	1.04	1.30	9.49	10.57	42.00
1903	8.94	1.83	2.50	.62	.29	1.29	.07	.31	.89	3.01	7.74	2.73	30.22
1904	3.91	8.96	6.70	1.46	.13	.52	.15	.38	.32	2.02	4.58	6.06	35.23
1905	4.32	1.22	3.74	.41	1.66	1.22	.05	.31	1.67	3.57	2.04	4.81	25.12
1906	2.82	4.87	1.63	.75	1.52	.63	1.97	.00	1.49	2.87	10.54	7.24	35.71
1907	5.97	3.72	3.32	4.86	.37	.40	.10	.42	.66	.37	4.55	8.60	33.43
1908	3.60	2.15	4.47	1.45	.90	.40	.13	.90	.05	4.10	2.20	5.70	26.05
1909	4.19	4.50	1.20	.46	.27	Tr.	.45	Tr.	.45	1.75	11.75	1.86	26.88

THE DALLES, OREG.

1850	.....	.....	.....	.....	.....	.....	0.01	0.00	0.09	0.91	1.14	0.19	.....
1851	3.81	1.70	1.79	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1852	.....	.....	.....	.....	.....	.....	.....	.....	.....	.25	2.75	8.01	.....
1853	3.02	1.09	.27	1.29	0.62	0.00	.08	.61	1.41	.24	4.90	.95	14.48
1854	2.79	.73	.36	1.52	.00	.15	.00	.18	.84	1.91	1.41	2.50	12.39
1855	3.03	.63	1.87	.17	1.08	.24	.10	.00	.60	.15	1.44	2.24	12.90
1856	.....	.54	.91	.79	.....	.....	.....	.....	.....	.....	3.50	10.79	.....
1857	7.08	1.85	2.83	.00	.23	1.02	.58	.00	2.70	.25	5.38	7.42	29.34
1858	5.60	9.41	2.91	1.36	1.70	1.03	.00	.75	5.16	3.32	6.48	5.83	43.65
1859	5.33	6.00	6.07	2.00	1.27	.20	.06	.47	5.77	2.14	4.25	3.66	35.96
1860	5.30	2.00	1.33	.83	1.73	.59	1.83	.40	.35	.48	3.46	3.47	21.32
1861	2.68	3.26	1.59	1.46	1.34	2.08	.00	.14	.33	.75	6.97	8.25	28.85
1862	4.47	2.25	3.54	.20	2.61	1.03	.22	.07	.64	.43	.20	.63	16.29
1863	3.38	2.17	.62	.48	.65	.11	.88	.08	.30	.48	.74	4.11	14.00
1864	5.88	.22	.....	.....	.09	.36	.....	.....	.16	.27	1.44	2.95	.....
1865	4.00	1.66	1.52	.06	.00	.08	.55	.57	.59	2.06	6.37	2.55	26.18
1866	6.35	2.83	5.56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1875	4.17	.31	2.13	.59	.81	1.65	.14	.12	.72	4.80	6.18	4.80	26.42
1876	2.76	1.39	2.20	1.09	.20	.34	.07	.02	.13	2.37	4.31	.46	15.34
1877	.78	1.68	3.66	1.21	1.03	.15	.48	.10	1.24	1.66	4.18	1.58	17.75
1878	2.96	2.32	1.99	.20	.26	.02	.08	.13	1.01	1.53	1.22	1.61	13.33
1879	1.43	6.32	3.15	1.34	2.94	.11	.31	.48	.79	.88	1.24	2.57	21.56
1880	2.04	1.33	.16	1.03	.94	.02	.02	.43	.08	.12	.69	6.75	13.01
1881	6.37	6.23	.38	1.29	.14	1.82	.11	.23	.26	2.62	.75	1.76	21.96
1882	1.49	2.92	.23	.53	.27	.60	.12	.72	.43	2.30	.75	5.14	15.50
1883	4.85	.61	2.32	1.21	.54	.01	.00	.00	.01	.46	2.19	1.77	13.97
1884	1.33	3.10	.74	1.33	.69	.93	.44	.12	.65	1.27	.82	7.04	18.46
1885	1.10	2.88	.14	.31	.81	1.01	.00	.00	.87	.28	1.78	2.64	11.82
1886	5.45	.53	.95	.30	.11	.07	.00	.02	.14	.70	.21	5.06	13.54
1887	4.01	1.13	.79	.46	.32	.67	.00	.18	.36	.15	1.06	3.01	12.14
1888	3.36	.41	.94	.05	.70	.92	.29	.00	.02	.95	1.34	2.71	11.69
1889	.51	.04	1.26	.42	.66	.29	Tr	Tr.	.26	.90	1.27	2.00	7.61
1890	2.97	4.33	1.79	.24	.04	.27	.06	.04	.11	1.16	.00	1.19	12.20
1891	1.13	2.47	.53	.01	.32	.51	.24	.11	.13	1.14	1.39	4.14	12.12
1892	1.35	.68	.70	1.00	.67	.06	.27	Tr.	.14	.90	1.16	5.04	11.97
1893	.69	1.84	.96	1.69	.69	.06	.30	.00	1.21	4.40	4.36	1.77	17.97
1894	4.84	1.83	3.73	.64	.47	1.15	.10	Tr.	1.02	2.08	.51	1.65	18.02
1895	4.72	.47	.65	.24	.94	.00	.32	.05	1.14	.00	1.20	4.15	13.88
1896	3.45	.72	1.00	.95	.63	.10	Tr.	.28	.42	.60	5.87	2.74	16.76
1897	1.14	2.98	1.94	.23	.27	1.07	.24	.08	.54	.24	3.84	4.03	16.60
1898	.82	.98	.30	.11	.03	.90	.17	.02	.85	.13	2.13	1.14	7.58
1899	2.82	2.19	.94	1.05	.45	.20	.00	.86	.81	1.56	3.57	2.29	16.74
1900	1.90	1.94	1.62	.42	.03	.47	Tr.	.55	1.09	2.02	2.25	1.33	13.62
1901	3.46	4.15	.68	.09	.39	.20	Tr.	.16	1.84	.13	1.69	3.04	15.83
1902	1.61	3.79	.52	1.82	.63	.13	.26	.00	.36	.78	3.53	4.00	17.43
1903	2.87	.47	.56	.23	.05	2.11	.12	.11	.15	.10	4.44	.56	12.77
1904	1.52	4.50	3.10	.98	.09	.46	.40	.04	.61	1.44	1.01	1.79	15.94
1905	3.27	.51	.63	.18	.66	1.27	.19	.10	1.19	1.98	.84	1.07	11.79
1906	1.90	1.67	1.21	.11	.95	1.05	Tr.	.31	.35	.23	3.99	3.07	14.84
1907	3.92	3.08	1.30	1.67	.14	.42	.22	.74	.29	.29	2.22	5.50	20.06
1908	1.06	.77	1.50	.17	.92	.10	.30	.16	.03	1.42	.48	1.21	8.18
1909	4.06	1.41	.33	.08	.13	.13	.39	.00	1.05	.83	4.55	3.09	16.05

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Precipitation at rainfall stations in and near area considered—Continued.

PINE HILL, NEAR LYLE, WASH.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1892	.....	.....	.....	.....	.....	.....	0.26	Tr.	0.36	1.14	2.43	6.11	.....
1893	1.28	4.15	2.27	2.65	1.03	0.16	.25	.....	2.57	7.03	6.03	3.84	.....
1894	6.66	3.44	8.10	1.13	1.01	2.06	.24	Tr.	1.88	2.79	1.66	3.58	33.15
1895	7.21	.83	1.84	.69	2.25	Tr.	.40	.12	1.15	Tr.	1.66	9.27	25.42
1896	4.42	2.23	2.65	2.09	1.90	.23	Tr.	.62	.64	1.12	9.95	4.59	30.44
1897	2.16	4.97	3.61	.50	.52	.89	.28	.10	.92	.57	6.34	7.82	28.68
1898	1.89	2.69	.78	.33	.26	1.03	.25	.01	1.95	.54	4.34	2.13	16.20
1899	6.60	3.60	1.63	1.98	.64	.35	.00	1.24	.89	2.19	5.97	3.49	28.58
1900	3.07	3.41	2.50	.77	.29	.75	Tr.	.12	1.16	3.07	5.00	3.49	23.63
1901	6.72	7.31	1.90	.97	.35	.47	Tr.	.23	2.01	.18	3.84	4.10	28.08
1902	2.68	6.01	1.49	2.40	.83	.12	.30	Tr.	.69	.92	5.64	7.72	28.80
1903	4.52	1.27	1.36	.35	.11	2.00	.02	.21	.60	2.22	6.05	1.59	20.30
1904	2.63	6.90	4.96	1.40	.19	.71	.29	.38	.60	2.00	2.10	4.03	26.19
1905	3.88	.97	1.82	.23	1.00	1.23	Tr.	.32	1.26	2.68	1.71	3.10	18.20
1906	2.79	3.29	2.07	.33	1.28	1.96	Tr.	.06	1.11	1.14	7.24	5.07	26.34
1907	6.66	4.89	1.51	2.73	.56	.51	.33	.28	.49	.41	4.69	8.50	31.56
1908	1.64	1.46	2.02	.66	1.14	.....	1.02	.65	.06	2.57	1.50	3.33	.....
1909	6.03	3.08	.64	.23	.18	.62	.45	Tr.	1.07	1.72	11.59	.....	25.61

GOLDENDALE, WASH.

1905	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.98	1.72	.....
1906	(2.8)	2.35	1.70	0.18	1.05	1.00	0.10	0.02	0.68	0.40	4.54	3.36	18.2
1907	.....	2.30	1.92	1.55	1.98	.....	.....	.....	.....	.....	.....	.....	.....
1908	.....	.41	.68	.41	1.20	Tr.	.02	.40	.....	1.90	.....	.....	.....
1909	.....	.....	.....	.....	.....	.....	.....	.00	.38	1.43	5.08	3.35	.....

FORT SIMCOE, WASH.

1857	.....	.....	.....	0.00	0.04	0.04	0.11	0.00	0.03	0.32	0.73	.....	.....
1858	2.11	4.54	1.06	.49	.54	.48	.03	1.04	.85	.83	.84	0.95	13.76
1859	2.50	1.19	1.38	.50	.....	.....	.....	.....	.....	.....	.....	.....	.....
1891	3.17	2.48	1.05	.00	.44	.62	.19	.14	.06	.58	1.02	3.81	13.56
1892	2.60	.18	.62	.68	1.42	.06	.00	.00	.38	.78	2.25	3.35	12.34
1893	1.00	3.45	1.15	1.30	1.12	.11	.61	.00	.32	1.33	2.59	1.30	14.28
1894	1.45	1.28	2.18	.73	.90	.33	Tr.	.00	Tr.	1.55	.99	3.20	12.67
1895	6.15	.40	.60	.20	.67	Tr.	.12	.00	1.65	.00	.66	2.81	13.26
1896	3.12	1.43	1.24	.80	1.14	.17	.00	.54	.12	.03	6.89	2.30	17.78
1897	.78	1.76	.69	.09	.32	1.15	Tr.	.00	.48	1.39	5.47	4.75	16.88
1898	.40	1.54	Tr.	.02	.18	.35	.00	.26	.48	Tr.	1.49	1.50	6.22
1899	3.71	.92	.22	.25	.64	.13	.00	.62	.34	1.25	4.03	.....	.....
1905	.....	.....	.....	.....	.....	1.82	Tr.	.36	.40	1.66	.70	1.15	.....
1906	1.61	2.07	1.39	.05	1.56	.09	Tr.	Tr.	.00	.22	5.41	3.26	.....
1907	3.86	1.85	2.03	.81	.46	2.05	.20	.20	.....	.....	.....	.....	.....
1908	.....	.03	.52	.35	1.27	.00	.12	.17	.00	.98	.....	.43	.....
1909	5.45	2.12	.59	.10	.01	.45	.66	.00	.40	.51	5.71	2.12	18.12

PLEASANT GROVE, NEAR ELLENSBURG, WASH.

1884	3.40	1.98	0.62	1.26	0.17	0.47	1.16	Tr.	0.33	0.71	0.16	2.97	.....
1885	.90	.44	Tr.	.03	1.18	.57	.01	Tr.	.39	.06	1.69	1.55	.....
1886	2.62	.30	.24	.98	.....	.....	.....	.....	.....	.....	.....	.....	.....
1892	.05	.27	.52	.62	1.84	.16	.35	0.00	.13	.50	1.32	.....	.....
1893	.19	1.21	.84	2.17	1.38	.....	.47	.00	1.11	.71	1.65	.33	.....
1894	1.21	.81	1.03	67	.46	.53	.00	.00	.13	.94	.99	1.04	7.81
1895	2.37	.25	.02	.18	.62	Tr.	Tr.	Tr.	.98	.00	.20	2.25	6.87
1896	1.89	.58	.71	.94	1.26	.17	.00	.....	.63	.22	3.45	1.36	.....
1897	1.62	1.93	.15	.08	.42	.80	.17	.....	.19	.47	3.92	2.93	.....
1898	.36	.47	.12	.03	.12	.73	.05	.29	.22	.22	.56	.54	3.71
1899	2.44	1.68	.18	.10	.39	.19	.05	.99	.40	.65	2.27	.58	9.92
1900	.97	.70	.91	.50	.42	.05	.10	.23	1.40	.98	1.27	1.14	8.67
1901	1.97	1.74	.31	.32	.88	.29	.00	.03	.52	.27	2.20	.89	9.42
1902	1.26	3.20	.43	1.79	.66	.05	.51	.00	.17	.74	1.53	3.24	13.58
1903	.67	.28	.27	.51	.10	1.28	.05	.30	.69	.60	3.59	.41	8.75
1904	.56	2.37	2.32	.73	Tr.	.63	.40	.28	.20	.19	1.25	1.44	10.37
1905	1.81	.36	.41	.16	.54	4.54	.15	.34	.38	1.42	.47	.77	11.35
1906	1.08	1.20	1.02	.00	1.23	.87	.09	.33	.27	.20	3.20	2.81	12.30
1907	2.09	1.33	.62	.30	.38	1.37	.27	.40	1.20	.29	.66	2.12	11.03
1908	.82	.79	.61	.18	1.42	.10	1.67	.04	.04	1.31	.70	.42	8.10
1909	2.31	.86	.36	Tr.	.26	.41	.89	.00	.56	.58	2.71	1.08	10.02

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Precipitation at rainfall stations in and near area considered—Continued.

YALE, WASH.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1906				2.16			0.00	Tr.	9.55	12.53	22.66	19.37	
1907	12.14	9.84	7.14	6.44	2.54	2.59	1.16	2.18	3.52	2.63	15.49	20.85	87.12
1908	10.86	8.56	18.50	7.28	7.51	2.77	.36	3.92	.95	10.45	7.15	14.45	92.76
1909	14.69	16.62	6.16	3.82	4.86	1.20	3.34	.23		6.55	31.02	6.57	

OLYMPIA, WASH.

1877							0.24	1.64	6.64	7.00	19.88	11.73	
1878	9.82	14.20	7.90	1.21	1.36	0.24	.98	.32	4.87	4.32	11.09	7.03	63.34
1879	5.96	15.59	14.44	2.10	4.72	.44	2.62	2.11	2.38	6.17	5.49	11.42	73.44
1880	19.69	5.16	5.57	2.47	4.10	1.44	.52	.22	1.05	2.83	3.06	16.66	62.77
1881	8.90	16.28	4.03	4.93	1.51	1.93	.98	.71	2.47	8.18	6.75	8.86	65.56
1882	6.11	9.60	2.24	4.57	2.30	1.00	.67	.81	1.24	6.96	5.77	10.32	51.59
1883	5.68	3.18	2.99	10.78	2.55	.21	Tr.	.01	2.24	3.73	5.10	5.14	41.61
1884	5.47	4.17	1.57	3.60	1.46	3.20	.60	.96	3.06	4.30	1.37	5.82	35.58
1885	6.23	7.67	.50	.39	2.84	.79	1.10	.00	3.69	2.84	10.18	5.72	41.95
1886	9.47	3.39	4.07	4.04	1.90	1.26	1.15	.42	3.17	4.15	1.73	13.38	48.13
1887	9.83	4.28	10.60	3.94	5.66	1.01	.74	.18	3.34	1.51	4.94	15.75	61.78
1888	11.38	2.71	5.96	1.72	.21								
1891	5.15	4.80	3.04	4.89	1.95	3.56	.23	1.36	3.65	5.66	10.83	13.61	58.73
1892	4.26	1.98	2.53	5.45	2.22	1.17	.88	.68	3.49	3.25	12.74	10.76	49.41
1893	2.21	8.51	5.71	10.18	3.58	2.43	.19	.47	2.21	5.59	12.86	7.68	61.62
1894	10.14	7.37	8.89	3.75	1.56	2.40	.37	.13	3.66	7.17	8.37	4.76	58.57
1895	9.85	2.77	4.47	4.46	5.93	.05	.35	Tr.	1.56			14.96	
1896	10.86	6.53	3.59	4.06	3.98	1.31	.00	.83	2.30	3.88	13.98	14.14	65.46
1897	5.81	6.58	6.29	1.28	1.02	1.49	.89	.36	2.62	1.55	13.01	17.60	58.50
1898	3.96	9.47	1.98	2.10	1.96	2.68	.28	.50	4.61	2.51	6.84	5.33	42.22
1899	12.60	5.99	3.37	5.63	3.39	1.23	.02	1.37	1.97	4.69	14.63	7.33	62.22
1900	5.96	5.37	6.89	1.84	5.34	3.75	.28	.68	1.86	8.26	6.11	10.03	56.37
1901	8.57	7.16	4.25	7.24	3.06	1.04	.49	.12	2.69	2.94	11.52	6.01	55.09
1902	7.15	11.68	6.78	5.17	2.43	.74	1.76	.24	2.71	2.98	15.09	14.04	70.77
1903	11.27	2.80	7.77	3.92	2.16	3.10	.46	1.18	3.64	4.06	11.72	4.80	56.88
1904	7.88	12.17	9.30	3.64	.69	1.68	1.79	.43	.21	2.33	13.23	8.32	61.67
1905	6.14	4.17	5.12	.71	2.85	3.18	.66	.30	3.33	7.36	3.73	8.88	46.43
1906	8.57	5.16	1.41	1.41	4.77	3.74	.30	.02	5.24	6.33	16.43	10.48	63.86
1907	7.22	5.43	3.24	3.79	.97	1.50	1.22	1.03	3.79	.99	10.47	12.03	51.68
1908	6.63	8.00	8.38	4.75	2.68	.21	.41	1.28	.19	4.26	6.75	9.84	53.20
1909	10.79	10.79	3.02	.77	2.02	.77	1.22	.21	1.14	4.27	19.44	6.30	60.74

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 254

THE UNDERGROUND WATERS OF NORTH-CENTRAL INDIANA

BY

STEPHEN R. CAPPS

WITH A CHAPTER ON

THE CHEMICAL CHARACTER OF THE WATERS

BY

R. B. DOLE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1910

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UNDERGROUND WATERS OF NORTH-CENTRAL INDIANA.

By STEPHEN R. CAPPS.

INTRODUCTION.

NEED OF INVESTIGATIONS.

The region discussed in this report includes an area of 7,611 square miles in north-central Indiana, between 85° 27′ and 86° 44′ west longitude and 39° 36′ and 41° 46′ north latitude. The counties included are Hendricks, Marion, Hancock, Boone, Hamilton, Madison, Clinton, Tipton, Carroll, Howard, Grant, Cass, Miami, Wabash, Fulton, Marshall, Kosciusko, St. Joseph, and Elkhart. (See fig. 1.)

The work was undertaken during the season of 1907 as a part of the underground-water investigations of the United States Geological Survey. The object of these investigations is to supply to communities, municipalities, and water users generally definite information as to the quantity, quality, distribution, accessibility, and proper safeguarding of the ground-water supplies, which, with the increasing pollution of surface waters by industrial wastes and a growing population, are becoming more and more important. North-central Indiana includes not only many closely settled farming and manufacturing centers, but a region in which there has been extensive development of the oil and gas industries, and hence there is particular need for reliable information upon which to base a proper practice in water-supply development. In such development in the future ground waters will share as they have in the past. They are utilized for domestic supplies, for manufacturing enterprises of various sorts, and by railroads and other users of steam power. In some places large sums have been wasted in unwise attempts at development, as, for example, in deep drilling at points where a careful study of conditions proves that suitable supplies are to be found at shallow depths or not at all.

PREVIOUS WORK.

In 1899 a paper on the wells of northern Indiana, by Frank Leverett,[a] was issued by the Geological Survey. Although Mr. Leverett collected the material for this paper during his investigations of the

[a] Wells of northern Indiana: Water-Supply Paper U. S. Geol. Survey No. 21, 1899.

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glacial geology of the State and was not directing his attention particularly to the conditions of water supply, his results were found to be of such value that the edition of his paper was soon exhausted.

W. S. Blatchley,[a] of the Indiana Geological Survey, has published an excellent paper on the mineral waters of Indiana. This paper,

FIGURE 1.—Index map showing area covered by this report.

as its title indicates, deals only with a special phase of the general problem. In the sixteenth report of the state geologist of Indiana, the records of many deep wells are given, and a number of these records are used in the present paper.

[a] Blatchley, W. S., Mineral waters of Indiana: Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1901.

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The report of the Indiana state board of health for 1906 includes a description of the public water systems of the State. This paper, by H. E. Barnard, although brief, contains valuable data. Other scattered references to underground-water conditions occur in the various reports of the Indiana Geological Survey, but these reports are not complete for any considerable areas.

In this report many valuable data have been taken from the various reports of Frank Leverett, especially in regard to the glacial geology of the area. The map of the glacial geology (Pl. I) is compiled from his earlier maps and from an unpublished map which will appear more fully under his name in a report of this Survey which is now in the hands of the printer. The geologic map in this report follows the geologic map of Indiana, by T. C. Hopkins,[a] and the geologic section is compiled from sections published by W. S. Blatchley and George H. Ashley,[b] and by Frank Leverett.[c]

CONDITIONS UNDER WHICH WORK WAS DONE.

The field work upon which this report is based was begun July 1, 1907, under the direction of F. G. Clapp. Mr. Clapp remained in the field until September 10, and the writer until November 9, of the same year. After Mr. Clapp withdrew from the field to undertake investigations elsewhere, the northern four counties were investigated wholly by the writer, by whom the report on the whole area was prepared.

The field study of the geology of this region was necessarily confined for the most part to the Pleistocene deposits, since the underlying rocks outcrop at the surface at widely separated localities, because of the thick mantle of glacial deposits overlying them. But wherever rock outcrops could be found they were studied carefully, especial attention being paid to joints, bedding planes, and other openings with reference to their capacity for holding or affording passage for underground waters.

Every township and every community of 25 people or more was visited and an examination made of the conditions of the local water supply. It was not possible to visit each well, but when such visits were impracticable correspondence with the owners yielded much information.

GENERAL SUMMARY OF RESULTS.

In the area under discussion a great variety of conditions are met in endeavoring to obtain supplies of underground water. About two-thirds of the area is covered with drift to a depth of over 100 feet, and in such places by far the greater number of the wells obtain

[a] Hopkins, T. C., Geological map of Indiana: Indiana Geol. Surv., 1901-1903.
[b] Rept. Indiana State Geologist, 1897.
[c] Water-Supply Paper U. S. Geol. Survey No. 114, pp. 258-263.

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their water from the drift. In the areas where the drift is less 100 feet thick the conditions also vary greatly. Where rock a depth of 30 feet or less the greater number of wells reach or trate the rock. Where the drift is more than 30 feet thick less half the wells reach the rock. This 30-foot dividing line is approximate, however, and the conditions vary in different loca As driven and drilled wells become more common the numb them that reach the rock increases.

There are few places in the area where enough water for dom purposes can not be obtained at moderate depths. Difficulti often met, however, in obtaining wells of sufficient yield for p supplies or for manufacturing purposes where large quantit water are needed.

In order that the sources of the most abundant and acce water supplies in this area might be reported upon definitely conditions in 378 cities, towns, and villages were investigated, considerable amount of work was done in the country districts be these communities.

Especial attention was paid to the water conditions in comm ties having public supplies. Recommendations are herein ma to possible improvements where such supplies are inadequate or bad sanitary conditions.

More or less complete records of about 1,200 wells were proc The more significant of these in each county, as well as the ana of the various waters, are tabulated at the end of each co description.

In all, 83 areas in which flowing wells occur were visited and outlines mapped. These areas are discussed in the county de tions, and suggestions are made as to the possibility of obta flowing wells.

ACKNOWLEDGMENTS.

From the nature of the work it was necessary that inform should be obtained from a very large number of persons, of who is impossible to make individual mention but to all of whom th are due for courtesies rendered. To Dr. J. N. Hurty, secretary o state board of health, and to Dr. H. E. Barnard, chemist of the board of health, the thanks of the author are particularly due for c tesies in analyzing water samples and for other assistance. In congressional district the Representative gave valuable information aid. The officials of the various railroads in the area have been formly courteous in furnishing information concerning the wa along their lines. A large number of chemical analyses and records were obtained from the files of the Pittsburg, Cincinnati, cago and St. Louis Railway, the Lake Erie and Western Railr the Cleveland, Cincinnati, Chicago and St. Louis Railway, the L

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Shore and Michigan Southern Railway, and the Erie Railroad. Records of a great number of oil and gas wells were obtained from Mr. L. A. Von Behren, of the Marion Gas Company; Mr. Charles Dale, of the Cicero Gas Company; Mr. Sherman, of the Noblesville Gas and Improvement Company, and many others. Material assistance was rendered by the majority of the superintendents and chief engineers of the city waterworks of the region, among whom Mr. H. McK. Landon, of the Indianapolis Water Company, and Mr. E. E. Hully, of the Marion Water Works Company, furnished especially valuable data. Of the many well drillers who were seen, the following made some sacrifice of time to give information: Messrs. John E. Weigel, of Marion; Charles Million, of Lake Cicott; the firm of Linton & Graf and Mr. Wm. H. Hayworth, of Logansport; Messrs. D. M. Kimmerling, of Anderson; S. Mason, of Fisher's Switch; Patrick O'Shea, of South Bend; and T. F. Hersey, of Lebanon. In addition to the foregoing a number of other citizens have taken interest in the work and given exceptional assistance in various ways. Among these are: The Hon. C. B. Landis, of Delphi; Mr. T. E. Cartwright, of Summitville; Dr. C. W. Burket, of Warsaw; Mr. Cicero Simms, of Frankfort; and Mr. S. T. Mark, of Alexandria.

GEOGRAPHY.

DRAINAGE AND RELIEF.

General relations.—Except Elkhart County and parts of St. Joseph and Kosciusko counties, which drain by St. Joseph River into Lake Michigan, and a considerable portion of St. Joseph and Marshall counties, which drain by Kankakee River into Illinois River, the area under discussion lies in the Ohio River basin. It is a plateau from 700 to slightly more than 1,000 feet above sea level. Only the deeper river valleys fall below the lower limit, White River at the south edge of the area having an elevation of less than 700 feet, while Wabash River, at the west-central edge, has incised its valley considerably below the 600-foot level. The total range in elevation is about 450 feet. (See Pl. I.)

Wabash River system.—The largest and most important drainage basin of this region is that of Wabash River. This stream flows somewhat south of west across Wabash, Miami, Cass, and Carroll counties. It has a deep, well-developed valley, which is cut 100 to 150 feet below the level of the bordering uplands. The flood plain of the stream varies in width from one-fourth mile to 2 or 3 miles, and is generally limited by bluffs of Niagara limestone, into which the valley has been cut. Wabash River and its tributaries drain about 4,050 square miles of the region under discussion, considerably more than one-half the whole area.

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The most important tributaries of the Wabash are (1) Mississinewa River in Miami, Wabash, and Grant counties; (2) Eel River in Kosciusko, Wabash, Miami, and Cass counties; (3) Tippecanoe River in Carroll, Kosciusko, and Fulton counties; (4) Pipe Creek in Cass, Miami, and Grant counties; (5) Wild Cat Creek in Carroll and Howard counties; (6) Eel River in Cass, Miami, and Wabash counties.

White River system.—Next in importance to the Wabash basin in respect to the area drainage is the basin of West Fork of White River, with an area in this district of about 1,900 square miles. The stream flows west and south across Madison, Hamilton, and Marion counties and furnishes water for a number of the larger cities along its banks. The only important tributary within this area is Fall Creek, which flows through the same counties as White River but lies farther south and east.

Most of Hancock County and small areas in eastern Marion and southern Madison counties drain through Sugar and Brandywine creeks and their tributaries into East Fork of White River. Neither of these creeks is notable for its size or for the development of its valley.

Kankakee River system.—The northern two-thirds of Marshall County and the south and west parts of St. Joseph County are drained by Kankakee River and its tributaries. The river flows southwestward through the Kankakee marsh and joins Desplaines River below Joliet, Ill., to form Illinois River.

St. Joseph River system.—In the northeast corner of the region there is an area of about 700 square miles, including Elkhart and parts of St. Joseph and Kosciusko counties, which is tributary to St. Joseph River. This river flows into Lake Michigan and belongs to the great St. Lawrence drainage basin. It makes a loop southward from Michigan into Elkhart County and flows west-southwest to South Bend, at which city it turns sharply northward and reenters Michigan. Elkhart River, its only important tributary in Indiana, traverses Elkhart County from south to north and receives the drainage from a part of northern Kosciusko County.

Lakes.—Scattered throughout the morainic portions of this region are many small lakes and ponds. Almost without exception these lakes occupy basins left in the irregular surface of the glacial moraine deposits. Kosciusko County alone has over 60 such lakes, and they are numerous in St. Joseph, Elkhart, Marshall, and other counties. In spite of the abundance of these bodies of water there is none of great size. Wawasee and Syracuse lakes in northeast Kosciusko County are connected and form the largest lake in the area. They are together 6 miles long and have an area of a little more than 5 square miles. Some of these lakes, including Maxin-

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kuckee, Wawasee, and Winona lakes, have become popular as summer watering places.

Marshes.—Much the same agencies that produced the lakes of this region have caused the extensive marshy areas that have existed, especially in the northern counties. Considerable areas in Fulton, Marshall, Kosciusko, and St. Joseph counties were formerly so marshy that cultivation was out of the question. Much has been done in the last generation to reclaim these wet lands, and networks of drainage ditches have so reduced the water level in some of the marshes that they are now annually plowed without great inconvenience from the moisture. The ditching is still in progress and the area of the waste lands is being rapidly reduced. Ditching projects have been especially successful in Cass, Kosciusko, and Marshall counties, and in these and in St. Joseph County are the largest of the areas still to be drained.

CLIMATE.

Northern Indiana is a region of temperate climate and moderate rainfall. The following tables show the temperature and precipitation for some stations within the area from 1900 to 1906, and by months for 1907. It will be seen that the highest temperature recorded in this period was 106° F., at Indianapolis in the summer of 1901, and the lowest was −24° F., at Delphi in the winter of 1905. These were both exceptional seasons, the average range of temperature for these cities being less than 110°.

Temperature at seven Indiana cities, 1900–1906.

[Degrees Fahrenheit.]

	1900.			1901.			1902.		
	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
Anderson	94	−7	.....	104	−11	51.2	93	− 7	51.8
Delphi	97	−7	51.6	104	−12	49.9	95	−12	49.9
Indianapolis	94	−7	54.0	106	−10	52.0	93	− 5	52.4
Kokomo	93	−6	52.7	102	− 9	.....	94	− 7	51.4
Logansport	95	0	52.1	105	−12	50.2	96	−11	50.7
Marion	98	−9	52.7	105	−12	50.9	97	−10	51.2
South Bend	93	−9	50.9	103	−15	49.1	91	−11	49.5

	1903.			1904.			1905.			1906.		
	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.	Mean.
Anderson	96	− 8	51.1	92	−13	49.1	90	−17	50.9	93	−10	.....
Delphi	100	−12	49.4	95	−20	47.6	95	−24	49.3	96	−13	.....
Indianapolis	94	− 9	51.9	91	− 7	50.3	92	−16	51.8	92	− 2	.....
Kokomo	97	−10	50.7	.....	−12	.....	94	−20	50.3	96	−19	.....
Logansport	97	−10	.....	95	−15	47.8	96	−19	49.2	98	− 9	.....
Marion	97	−12	50.6	94	−18	48.2	95	−20	50.3	95	−14	.....
South Bend	93	−10	48.1	94	−11	45.7	.....	.....	.....	95	− 6	.....

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Precipitation at seven Indiana cities, 1900–1907.

[Inches.]

	1900.	1901.	1902.	1903.	1904.	1905.	1906.	1907.
Anderson	.....	28.68	39.20	34.68	40.61	45.33	32.85	43.33
Delphi	40.69	30.92	42.51	33.48	40.23	40.87	39.27	44.91
Indianapolis	38.45	30.33	37.70	32.46	45.42	33.27	36.47	38.56
Kokomo	40.65	31.37	40.86	31.50	.....	.....	35.97	38.54
Logansport	30.96	29.52	39.96	38.38	32.43	38.14	41.70	44.62
Marion	37.94	32.35	40.63	39.81	41.88	39.64	43.54	43.70
South Bend	34.55	30.93	41.53	42.32	31.47	39.27	35.53	43.58

Temperature at eight Indiana cities, by months, 1907.

[Degrees Fahrenheit.]

	January.			February.			March.			April.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Anderson	66	−1	33.0	59	3	28.7	82	20	48.0	75	22	42.3
Delphi	66	−2	29.8	58	0	26.4	85	17	44.8	80	19	41.4
Indianapolis	69	2	.....	63	6	.....	82	24	.....	75	27	.....
Kokomo	67	−3	32.8	59	−0	28.4	84	17	48.0	77	20	41.9
Logansport	65	−1	30.2	61	−0	27.2	86	18	46.6	78	20	42.4
Marion	65	−3	31.8	58	2	27.6	85	18	46.6	79	19	43.2
Rochester	60	−2	30.6	50	−1	26.5	75	20	44.6	69	21	41.4
South Bend	65	−4	26.7	53	−3	24.4	82	15	41.6	70	17	39.0

	May.			June.			July.			August.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Anderson	83	32	56.2	88	40	66.7	90	52	73.4	89	49	70.2
Delphi	84	28	54.8	92	42	66.8	93	45	73.6	94	45	70.0
Indianapolis	83	34	.....	88	45	.....	93	52	.....	90	54	.....
Kokomo	82	29	54.5	92	40	66.5	90	45	72.7	93	45	69.8
Logansport	85	30	55.8	94	44	68.2	93	46	75.2	95	46	71.2
Marion	84	28	55.2	93	38	67.2	91	48	74.2	92	45	70.5
Rochester	80	30	55.0	88	42	67.9	88	50	74.2	87	48	70.1
South Bend	80	26	51.9	90	45	65.6	87	47	71.0	90	45	69.0

	September.			October.			November.			December.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Anderson	86	37	64.9	82	20	51	61	18	39.3	60	10	33.4
Delphi	92	33	63.7	86	23	48.8	60	15	37	60	9	30.8
Indianapolis	87	40	.....	83	31	.....	58	20	.....	60	18	.....
Kokomo	90	33	63.4	85	25	49.4	58	15	39.1	60	11	34.6
Logansport	95	35	65	89	26	50.2	59	17	39	61	10	32
Marion	88	33	64.2	84	55	49.8	56	17	38.2	60	9	32.4
Rochester	85	37	63.2	72	27	49.3	55	19	38.1	55	10	31.8
South Bend	91	35	63	83	27	48.4	56	26	37.9	55	14	29.8

Precipitation at eight Indiana cities, by months, 1907.

[Inches.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Anderson	6.40	0.15	4.69	2.76	2.85	4.88	6.93	4.85	2.27	1.89	2.18	3.48	43.33
Delphi	7.00	.32	3.93	1.91	2.87	5.50	6.43	3.86	3.94	1.31	2.31	5.53	44.91
Indianapolis	7.68	.18	4.07	2.07	2.85	4.68	4.41	2.33	2.31	2.23	2.52	3.23	38.56
Kokomo	5.59	.04	3.80	2.08	3.15	4.45	4.88	4.05	2.51	2.42	1.74	3.83	38.54
Logansport	4.60	.35	3.92	1.71	4.07	6.38	5.79	6.13	2.71	1.70	2.42	4.84	44.62
Marion	7.01	.15	4.62	2.64	2.35	7.46	3.97	3.82	2.66	2.35	2.00	4.70	43.73
Rochester	4.80	.15	5.31	2.32	4.20	6.46	4.61	2.99	4.73	1.60	2.57	4.40	44.14
South Bend	3.42	.42	3.91	3.76	4.13	4.83	5.10	3.48	4.82	2.43	2.36	4.92	43.58

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The annual precipitation, which is rather evenly distributed, varies from about 30 inches in very dry seasons to over 40 inches in wet seasons, but even in the driest seasons there is usually enough rain to insure crops.

As the ground is frozen for about four months each year, and the precipitation then is of course in the form of snow, very little of it can enter the ground during that period. During the remaining eight months the soil is in condition to absorb large amounts of the rainfall, and this goes to swell the ground-water supply. The direct influence of the rainfall on shallow wells is noticeable wherever such wells are in use. During the spring, when the rainfall is heaviest, and when, in addition, the snows that have accumulated on the surface during the winter melt, the ground-water level often rises notably, sometimes filling wells nearly to the top and flooding cellars which are not tightly walled and floored. Later, in the dry summer months, the water table is lowered by evaporation from the surface, by leakage from springs and seeps along the lowlands, and by the drain upon the waters by vegetation and by wells. In seasons of exceptional drought the water table may be so lowered below the bottom of the shallower wells that they fail. Often if such wells are deepened a few feet the water table is again encountered, and the wells once more become productive.

The influence of climatic or seasonal conditions on the deeper wells is much less evident. In most deep-lying formations the movements of the water are very slow, and a change in the supply caused by seasonal conditions might be observable, if at all, not until long after the cause for the change had passed.

The waters in many deep water-bearing rocks are under hydrostatic pressure from a head at some distant point, and are separated from the surface by impervious beds. Under such conditions, changes in season or in rainfall in the area about the well would have no effect whatever upon the supply of the well, unless they also were effective in the region from which the water-bearing beds derived their supply.

NATIVE VEGETATION.

The greater part of northern Indiana was originally heavily timbered, and the timber lands still produce a considerable amount of saw logs. The white, red, and burr oak logs are much sought, and the best bring high prices from the manufacturers of furniture and veneer. Beech is the timber of next importance; hickory, elm, ash, and maple are also abundant.

The timber lands are now nowhere extensive, and have been reduced to small areas which are surrounded by cultivated fields. Carelessness and waste are still exhibited in the management of the

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timber lands and the cutting of timber, and a little study and care would greatly increase the future production of the forests, which become more and more valuable with the rapidly advancing price of lumber.

Undisturbed timber lands are admirable agents in the conservation of underground water. The thick loamy soil of woodlands, formed of decaying matted leaves and roots, is well adapted to retain moisture, and the shade of the forest greatly retards evaporation. By retaining the water that falls upon them the forest soils reduce the run-off and increase the quantity that sinks into the ground. Thus the forest lands act as reservoirs and assist in equalizing the ground-water supply. In the areas where all forests have been cut away and the fields put under cultivation it has been noticed that the water table has fallen, and wells which formerly furnished abundant water are now dry for part of the year.

SOILS AND CROPS.

The soils of northern Indiana, though varied, are for the most part rich, as are most of the soils in the Mississippi Valley which have been deposited by glacial agencies. Most of the farm lands have a soil composed of a mixture of oxidized glacial clay and organic material. The glacial till is a mixture of ingredients gathered from the country to the north, and the efficiency of this mixture has long been known from the large production of most of the areas which were fortunately coated with it. As far down as it reaches this till is fertile, and as the average thickness over northern Indiana is more than 100 feet, there is at least no immediate danger that the soils will be removed from this region by erosion. The glacial drift, originally bluish, has commonly been oxidized to yellow for a few feet below the surface.

In many areas which are or have been low and marshy there is a layer a foot or two thick of light, black soil largely composed of decomposed vegetable matter. This soil is locally called muck, and in certain sections it produces large crops of onions and potatoes. The vegetable matter has in some places accumulated in sufficient amount and purity to form a considerable layer of peat.

Along the bottom lands of both large and small streams are found the alluvial soils. The extent of these alluvial areas varies with the width of the valley bottoms, but wherever found they furnish most desirable farming land, unless the high waters from the streams flood them too frequently.

In the northern counties there are broad flat areas mapped by Leverett as sandy till plains (Pl. I), in which are various combinations of till-plain and outwash materials. As a whole the soils in these

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areas contain more sand and gravel than the soils of the typical till plains, as in much of western Kosciusko and eastern Marshall counties.

Along the west edge of Marshall, Fulton, St. Joseph, and Cass counties are areas where the surface materials consist for the most part of impure sands. These sandy areas are on the eastern edge of what was in glacial times a broad shallow lake, which has been named Lake Kankakee. The sands were deposited along the shores of the lake and winds have spread them over much country that never lay beneath the lake itself. The sandy soils are cultivated in many places, but will not support as heavy crops as the clayey soils.

Northern Indiana falls within the "corn belt," and a greater acreage is devoted to this cereal than to any other crop. Over much of the country wheat is a close rival at present, the high price of wheat in the past few years having caused much land which had previously been used for corn culture to be planted in wheat. Oats and other cereals are also important crops, while in some places onions and potatoes are cultivated almost to the exclusion of the grains.

SPECIAL FACTORS IN DEVELOPMENT.

Oil and gas.—Within the last twenty-five years rich strikes of petroleum and natural gas have been made in various parts of the area, and, as usual, many people have been attracted to the oil and gas fields. The oil was piped or hauled to various centers outside of the producing fields to be refined, but the gas drew to the fields a multitude of manufacturers who, seeing increased profits from the use of this cheap and abundant fuel, located their plants wherever the gas was to be had. A list of the various users of gas for manufacturing purposes in the year 1888 is given in one of the reports of the Department of Geology and Natural History of Indiana.[a] Since that report was published, however, the supply has diminished greatly and numerous wells have been abandoned. Some districts have "played out" entirely. Many factories found it impossible to operate successfully, and their vacant buildings are a common sight in the old gas fields.

Transportation.—The situation of the area gives it uncommon transportation facilities. All the railroads between Chicago and the East take courses south or southeast around the south end of Lake Michigan, and most of these roads cross the area considered in this report. In addition, a network of railroads crosses in other directions, and these roads, with the increasing number of electric interurban lines, afford exceptional opportunities for marketing crops and for easy communication between towns. The rapid development of the country is in large measure due to these conditions.

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., pp. 280–301.

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INHABITANTS.

The nineteen counties covered by this report have an aggregate area of 7,611 square miles. As shown by the census of 1900, the population was then 781,690, an average of 102 inhabitants to the square mile. The actual distribution of the population, however, is rather irregular. In Fulton County settlement is least dense, there being but 45 people to the square mile, while in Marion County the average is 493 to the square mile. This high average is due, of course, to the location in Marion County of Indianapolis, which is much the largest city in the State.

South Bend, the second city in size in the area, had, in 1900, a population of 35,999. There were at that time no other cities larger than 30,000.

Aside from the cities, the population throughout the nineteen counties is rather evenly distributed, and the larger counties have, in general, a proportionately large population.

GEOLOGY.

OUTLINE OF GEOLOGIC HISTORY.

Briefly, the geologic history of this area is as follows: For a very long period, during Cambrian, Ordovician, Silurian, Devonian, and Carboniferous times, the seas over this region varied in depth from time to time, giving the conditions necessary for the successive formation of sandstones, shales, and limestones to a thickness of several thousand feet. Between the deposition of the Cambrian and the Carboniferous sediments there were certainly a few and probably many periods when land emerged from the seas and was worn away by the streams, waves, and winds. After and probably during Carboniferous time there was a general emergence of this land from the water, and perhaps the area has never since been covered by the sea. At different times during the slow processes of sedimentation and of changes in the relations of land and sea stresses were set up in the rocks of the earth's surface at certain places and the beds were locally folded and distorted, as we can now see by the notable departure of the beds from the horizontal, as at Delphi. During this long period of emergence the land was subjected to the erosion of streams and other agencies and was doubtless notably reduced. The land surface was cut into ridges and valleys and the streams established well-developed drainage lines. This was the condition at the beginning of the glacial period.

The glacial period began when a great glacier slowly advanced from the north, covering the land with ice many hundreds and perhaps many thousands of feet thick. The more prominent irregularities of the rock surface were worn away and the topography was funda-

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mentally changed. In the course of time, from changes in climatic conditions, the glacier melted back far to the north, leaving behind it great quantities of detrital material. Later there came again at least one and perhaps more than one ice invasion, reducing still further the rock surfaces or overriding the former deposits and adding to the already enormous deposits of glacial débris.

With the final withdrawal of the ice the Recent period was begun. Since the beginning of this period the streams and other erosional agencies have been constantly at work, reestablishing drainage lines to replace those which the glaciers disturbed and placing under stream control the irregular surfaces of the glacial deposits. Much work still remains to be done by the streams before the marshes and lakes are all drained, but this work is being forwarded in a notable way by the artificial construction of drainage ditches.

RELATIONS OF GROUND WATER TO GEOLOGY.

A very intimate relation exists between the geology of a region and its underground water supply. With the temperate climate and abundant rainfall with which the area here under discussion is favored, the abundance of the ground water, the ease with which it can be obtained, and the character of the water depend in great measure upon the structure, texture, and composition of the materials which compose the upper portion of the earth's crust. The underground waters occupy the openings of various kinds which exist in the materials below the surface. With favorable conditions of topography, the underground waters will be easily available if such openings are numerous, large, and continuous, and will be difficult to obtain if the openings are few, small, and discontinuous. The chemical character of the water, too, is determined by the chemical composition of the materials through which it passes, by the solubility of the constituents, by the length of time the water remains in contact with the soluble elements, and by conditions of pressure, temperature, etc. A fuller discussion of the relation of the different types of materials to the underground waters will be given in the following pages. As the relation of the underground waters to the formations in which they occur is a definite one, it is possible, if the character, composition, and depth of the underlying formations are known, to predict with a considerable degree of accuracy the amount, character, and depth of the water which may be obtained by wells in a given place. A careful study of the geology and of the succession of geologic formations is therefore necessary for a proper interpretation of the facts collected in an investigation of this kind.

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EFFECT OF GLACIATION ON TOPOGRAPHY.

MOVEMENTS OF THE ICE.

Before the great ice invasions of the glacial epoch the topogr of this region was very different from that of the present. A time the great sheet of bowlder clay, now covering the region absent, and the then-existing surface forms were the result of e by preglacial streams in the rocks which at present underli mantle of glacial deposits. Most of these earlier stream valley courses very different from those followed by the present str and the surface of the country was much steeper and more r than it is now. Upon the advance of the great glacier from the all this was changed. The ice, moving slowly south, first rem all the soil and loose materials, and then, with its base shod fragments of rock frozen into the ice, gradually wore down the and smoothed off the most prominent irregularities. Great qu ties of rock débris were picked up and carried by this ice s Much of this material was collected from areas far to the north, which the ice came, and many bowlders of crystalline rock are tered over the surface and incorporated with the bowlder clay. there are no crystalline rocks in place for a long distance north o present position of some of these bowlders, it is certain that must have been carried far before they were dropped by the ice.

The materials which the ice gathered in its southward jou were deposited toward the south or melting edge of the gl Much was deposited beneath the thinning glacier edge as till, f depressions and grading over the worn rock surfaces. Many of stream valleys which had not been erased by the grinding actio the glacier were filled full and leveled over by the deposits of gl brought débris. Some such filled-in valleys can be recognized by lecting the records of well drillings, some of which show a depth to rock, while others near by reach rock at much shall depths. Such an old preglacial valley is that described by Bownocker,[a] which runs from the Ohio River Valley near Cinci north along the present Little Miami Valley, and then northwest west through Grant and into Wabash County. This buried ca certainly continues still farther north and west, but the dat present available are insufficient to determine its entire co There is some evidence that it follows the course indicated in P II, across Wabash and Miami counties.

It has been shown[b] that this region has been subjected to m than one glacial invasion, but it was the last ice advance that the greatest influence in molding the present surface, for the

[a] Ohio State Acad. Sci., Special Paper No. 3.

[b] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1898, p. 434.

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glacier rehandled and rearranged the materials which it found in its course and effaced the irregularities of the drift as left by its predecessor, while its own moraines are unmodified by destructive agencies except the slow ones of weathering and stream erosion since the withdrawal of ice.

MORAINES.

At the edge of the ice, as it covered this region, was deposited much of the material that it had picked up and carried with it. Many of these deposits form huge irregular ridges, which the ice left as it retreated, forming successive moraines farther and farther north. As the edge of the ice sheet was irregular in outline, and as the general retreat of the glacier was irregular and interrupted by short advances, the moraine deposits are most unsystematic. The ice at each advance would modify or destroy all the previously formed moraines over which it passed. These conditions account for the irregular and patchy distribution of the morainic areas, as shown on the map (Pl. I).

OUTWASH PLAINS.

At the base of many of the morainic deposits are plains of fine gravels, sands, and silts which slope at a low angle away from the morainic ridges. These plains were deposited at the time the glaciers were building the moraines. The abundant waters from the melting ice flowed away from the ice edges and carried with them large quantities of the finer débris. This material was deposited beyond the moraines and built up the gentle slopes there. It is in such deposits or in the irregular gravel beds of the moraines themselves that most of the gravel pits throughout the area are located.

TILL PLAINS.

Perhaps the most notable topographic feature of this area is the great extent of the plains formed of pebbly clay or till. These plains were built below the body of the glacier which was advancing over them, and the present level or slightly rolling surface of much of the country, especially south of Wabash River, is due to these deposits of till or ground moraine. The till is discussed more fully in the following pages.

SURFACE DEPOSITS.

GLACIAL TILL.

DESCRIPTION.

The term till has been applied to those clayey phases of glacial débris which were laid down by the great ice sheets that covered this area in Pleistocene times. It consists of a compact clayey matrix, through which are scattered pebbles, bowlders, and angular pieces

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of rock ranging from microscopic dimensions to a diameter of several feet. The rock fragments in this particular region are derived generally from the local limestones. There are many representatives, however, of the crystalline rocks of Canada that were brought hundreds of miles by the ice to their present resting place. The large bowlders in the till are usually of these more resistant crystalline rocks. At some places the till contains thin beds of rudely stratified gravels or sands, but these form only a small percentage of the total thickness.

DISTRIBUTION.

Originally the till sheet seems to have been continuous over the whole area. Postglacial erosion has now removed it from a few narrow strips along the valleys of the more important streams, but otherwise the till sheet is practically unbroken. It does not, however, outcrop everywhere at the surface. Plate I shows the present distribution of the till plains. Although much of the surface is now occupied by morainal deposits, outwash plains, and alluvium, the moraines and outwash deposits generally and the alluvium in most places are underlain by this great till sheet. The till varies in thickness in different parts of the area from a thin layer to more than 400 feet, and probably averages more than 100 feet thick throughout north-central Indiana (Pl. II).

TOPOGRAPHY.

The till, where not overlain by morainal deposits, has characteristically a very mild topography. Over entire townships there is often a range of only a few feet in elevation, with even the stream valleys less than a dozen feet below the level of the plain. The dead level of a perfect plain is usually broken by slight undulations or swells of 4 or 5 feet from trough to crest. This extensive till sheet forms the broad plateau of the whole region here discussed. The plateau surface ranges from a little below 700 feet to about 900 feet above sea level, and is broken by the valleys of the larger streams and by the more or less ridgelike, superimposed terminal-moraine deposits.

GROUND WATER IN THE TILL.

Source.—As it occupies the plateau tops and the crests of the stream divides, the till must receive most of its water from the rainfall. The flatness and imperfect drainage of much of its surface results in the absorption of a large proportion of the rainfall. In those areas where the till is overlain by gravelly morainic drift these more porous materials receive the rainfall and feed it to the underlying till. In places, too, there are deep preglacial valleys in the rock surface which have been filled with till, and here it doubtless receives some water from the rock. For the most part, however, the waters are absorbed directly from the rainfall.

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Distribution and circulation.—By far the greater part of the till is composed of a fine-grained clay, which has a rather large proportion of pore space, but in which the individual pores are small. In the flat areas the water table approaches close to the surface, and most of the body of this material is saturated with water contained in these pores. The thin beds of gravel or sand, or of gravelly or sandy clay, also have a large amount of pore space, with larger individual pores. In some of these beds, if they happen to be higher at one end than at the other, waters under artesian pressure are found, the more impervious clayey beds above and below being effective in preventing the dissipation of the head which the slope of the bed gives to the water.

Even in the close-textured portion of the till there is some circulation of the waters, but the movement is very sluggish. On the other hand, in coarse gravel beds in the till the circulation may be very rapid. There may be all gradations in rapidity of movement between these two extremes, the rate varying with variations in the texture of the material.

Types of wells.—In most till areas the amount of available water for well supply is small. The most common wells are open or dug, and these will generally supply sufficient water for domestic use. They have been locally called seep wells, from the slow way in which the water seeps out of the till, and definite water channels are rarely encountered in this material. Dug wells, while furnishing sufficient water for ordinary domestic use during most of the year, are apt to fail in exceptionally dry seasons when the water table has become lower than usual. Furthermore, the open shallow wells are always in danger of pollution from cesspools and barnyards, the drainage from which enters the ground and becomes part of the ground-water supply. Tubular wells that case off the surface waters are much safer and can more easily be put down to such depths that they will not be affected by drought. If tubular wells will not supply sufficient water, deep dug wells, open only near the bottom, and with tightly cemented walls and tops, are recommended.

MORAINAL DRIFT.

DESCRIPTION.

The terminal-moraine deposits in this region are formed largely of the same sort of materials as those which make up the till. They consist of a heterogeneous mixture of glacial débris, composed of great bowlders, pebbles, and blocks of rock mixed indiscriminately with sands and clays. The common matrix of this unstratified mass is a blue clay. The bowlders and bits of rock included in the drift are derived both from the native rocks of the area and from the crystalline rocks of the upper course of the glacier in Canada. Inter-

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bedded with the unassorted drift are numerous lenses or pockets of stratified sands and gravels, some lying flat and some much disturbed. The morainal drift differs from the till in that it has never been subjected to the great pressure of an overriding ice body, and has not had the glacial kneading and squeezing which has given the till its tough, compact character.

DISTRIBUTION.

The morainic tracts, of irregular shapes and distribution, were deposited at the ice edge during the retreat of the glacier. Doubtless many moraines that do not now exist were built while the ice was advancing or during temporary halts in the general period of advance. Such moraines, however, were overridden and obliterated by the southward-moving ice edge. Only those survived which were built on territory which the ice never again invaded. In an area in which the moraine material is thin or absent we may infer that the final ice retreat was continuous and rapid. The presence of a well-defined moraine ridge indicates that the ice edge was approximately stationary at this point for some time.

The distribution of the different morainic areas is shown on Plate I. It will be seen that, while scattered irregularly over the entire area, they are more prominent topographically and more continuous north of Wabash River than south of it.

The Maxinkuckee moraine extends, in this area, from Tippecanoe River in Fulton County north through Marshall into St. Joseph, and thence eastward through Elkhart County. Another, deposited between two lobes of the great glacier, extends from a point a few miles north of Delphi northeastward through Carroll, Cass, Miami, Wabash, and Kosciusko counties. The other moraines are smaller, more patchy in distribution, and of less vigorous development.

TOPOGRAPHY.

Since terminal moraines are deposited along the front of a glacier it is natural to expect them to be more or less ridgelike in form. This is true of the great belt which crosses parts of Cass, Miami, Fulton, Wabash, and Kosciusko counties from northeast to southwest, and of portions of the Maxinkuckee moraine. The smaller patches are ridgelike only in their general relations to the surrounding till plateau. The surface commonly consists of an irregular succession of sharp hills and basin-like depressions. Many of the depressions contain lakes or have been silted up to form marshes. In many parts the moraine surface is thickly strewn with bowlders, most of them of the resistant crystalline rocks.

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GROUND WATER IN THE MORAINAL DRIFT.

Sources and distribution.—All the moraines lie on top of the till plateau and stand up somewhat above their surroundings. Because of their elevated position the only source for the underground water of these deposits is the rainfall, a large part of which is absorbed by the porous drift. Some of it issues from the drift as springs or seeps near the base of the moraine, and some is fed to the underlying till.

In the moraines much of the water is held in the fine pores and gravelly portions of the unstratified clays. The clays give up their waters slowly, and wells in the bowlder clay, though commonly yielding enough water for household use, do not generally strike abundant supplies. Those wells which penetrate bodies of gravel or coarse sand, on the contrary, commonly yield largely, and it is from such open beds that most of the wells in the moraines obtain their water. The coarse gravel and sand beds are much more common in morainal drift than in the till plains, and as a result wells are more easily obtained and the water supplies are more abundant in the drift than in the till.

Types of wells.—Almost anywhere in the morainic areas tubular wells may be successful if they are continued downward to a bed of open material. Bowlders are encountered by many wells in the drift, causing difficulty, but most wells that avoid them are successful. Artesian wells are in some places obtained in the drift gravels and sands.

OUTWASH DEPOSITS.

DESCRIPTION.

Beyond the edge of a terminal moraine the till plain is in many places covered by an outwash plain formed while the moraine was being built. The abundant waters from the melting ice, heavily charged with débris from the glacier, built out alluvial fans of low slope from the base of the terminal moraine. In places the fans coalesced to form a continuous outwash plain or apron. Outwash plains are composed of imperfectly assorted gravel, sand, and silt. The individual particles of the beds are of the same materials which make up the moraines, but the assorting action of the waters has separated and arranged them, the coarser materials lying nearest the moraine and the finer farther away.

DISTRIBUTION.

While all the outwash plains are in close relation to the moraines next to which they were formed, such plains are not present beyond every moraine, but only where the slopes caused the glacial waters to flow out over a flat plain, as in northwest Kosciusko and eastern Marshall County (Pl. I). Where the waters drained into deep valleys and left their deposits in them, the chances were favorable for the postglacial removal of the outwash gravels.

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GROUND WATER IN THE OUTWASH DEPOSITS.

The outwash plains receive much of their water directly from the rainfall, and the porous materials of which they are composed readily absorb the water precipitated upon them. The moraines at their upper edge also supply them with water by seepage and by direct communication between the gravels.

In the open gravel and sand beds of an outwash plain the lateral movements of the water are free and may be very rapid. If a single bed is continuous from the upper to the lower edge of the plain and has an outlet for the water below, the movement of the water may be free enough to keep the gravel bed drained. If, on the other hand, such a bed were included between impervious beds and had no free outlet below, a considerable artesian head would develop toward the lower edge of the inclined plain. Such conditions are not uncommon, and in certain areas many flowing wells are supplied in this way.

The outwash materials have, as a rule, remained uncemented. The ground waters, therefore, are contained in the minute pore spaces of the fine materials and in the larger openings of the coarser sands and gravels. In the coarser deposits which compose most of the outwash plains a great portion of the contained water is available for well supplies, and the most common type of well is the driven well, usually only 12 to 15 feet deep. Driven wells may furnish an unfailing supply of water but are not safe from the pollution of privies, manured fields, etc. To be perfectly safe they should be driven to a water-bearing bed below an impervious clayey layer.

VALLEY ALLUVIUM.

CHARACTER AND DISTRIBUTION.

All the larger streams of the areas here discussed have broadened their valleys and built up flood plains along at least a part of their courses. Many of the smaller streams have patches of alluvial bottom lands along their valleys, but alluvial deposits reach especially notable size in the valleys of St. Joseph, Wabash, and White rivers. The deposits are composed of the roughly assorted detrital materials which the stream has carried and left in favorable localities. The materials are gravels, sands, and silts, derived from the glacial deposits and from any material over which the stream has traveled, and contain the native limestones and decomposed shales, as well as the glacier-borne erratic materials.

It is uncommon for one of the large streams of this area to occupy the whole of its valley bottom, and it does so only in flood season or where the stream flows over a rock ledge. The remainder of the valley floor is alluvial material. Generally this floor is below high-

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water level, and is overflowed in flood seasons. Above this at some places there are remnants of older, higher flood plains which now stand as terraces above the present river flat. The alluvial bottoms vary in width, the widest measuring 3 or 4 miles, and appear on an areal map as long, narrow areas following the courses of the larger streams.

GROUND WATER IN THE ALLUVIUM.

The valley alluvium, like the materials of the outwash plain, consists of uncemented, imperfectly stratified gravels, sands, and muds. In all these materials the waters are in the openings between the particles. As the amount of available water in muds and fine sands is small, it is necessary to reach coarse sands or gravels for successful wells. Few wells 8 to 15 feet in depth fail to enter such gravel beds, and abundant water is everywhere obtainable at little expense. Valley alluvium, from its nature, occurs in valley bottoms where the water table approaches the surface, and water is obtained with such ease that people often neglect to go a few feet deeper than the water table, though by so doing they might obtain a much safer and more palatable water supply.

Much of the water in alluvial deposits is directly absorbed from the rainfall, for the porous beds will readily receive large amounts of water. Perhaps still more important is the water received by seepage or springs from the materials which form the uplands. The valley sides may be composed either of till, as they are in most places, or of limestone or shale, or of morainic deposits. A common but erroneous idea is that the bottom-land waters are supplied by the streams that flow through them. The movement of the underground waters is from the uplands toward the streams; and instead of the stream supplying water to its banks, the banks are constantly augmenting the stream by the escape of their stored waters. Chemical analyses of the stream waters and of the ground waters of the bottom lands in this area show a great difference, the stream waters containing much less lime than the ground waters. Only at times when the streams rise more rapidly than the water table of their banks do the streams furnish any addition to the ground-water supply, and then only for a short time. (See fig. 4.)

In the open and more porous beds of valley alluvium the movement of the ground waters may be rapid. The water table of the uplands is higher than that of the valleys, and this causes the waters to move streamward. There is also some movement of the waters down valley. (See fig. 4.) Under favorable conditions artesian pressure may develop in alluvial deposits, the head being furnished by the higher water table of the uplands. (See figs. 8 and 9.)

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SAND.

DESCRIPTION AND DISTRIBUTION.

St. Joseph, Marshall, Fulton, and Cass counties, along their western edges, border on an area which, during the retreat of the last glacier, was occupied by a large lake, which has been called Lake Kankakee.[a] The basin which it occupied is now a sandy plain, and wind-blown sand tops the glacial clays for some distance east of the borders of the lake flat. The water-laid sands are in many places coarse or even gravelly, and were derived from the glacial deposits along the shores and shallows of the lake and from the débris dumped directly into the lake by the glacier. East of the shore of this extinct lake the sands, being wind sorted, are fine and contain little or no gravel.

Only a very small area of the region under discussion lies within the old lake basin, which is remarkably flat and featureless. Formerly the lake bed was an almost impassable marsh, but by systematic ditching much of it has been reclaimed. East of the lake basin the wind-blown sand has spread and emphasized the topography of the underlying drift. In some places small but distinct dunes occur.

GROUND WATER IN THE SANDS.

As the wind-blown sand lies altogether on the surface of the area in which it occurs, it is evident that its water is derived almost wholly from the rainfall. The lake-bed deposits, also, are largely dependent upon the rainfall for their water, although the bordering shores of glacial drift and dune sand supply some water to the sand beds.

The sandy deposits are unconsolidated and not subject to joints, so the contained water all occurs in the pore spaces between the rock particles. The pore space in sand is very large, ranging up to 35 or 40 per cent of the whole volume, and wells driven into the lake beds always get abundant waters close to the surface. In the wind-blown sands the pore space is large, but the particles are small and of uniform size, so that the sands have a habit of packing very closely. Drillers often have great trouble in finding a bed of material coarse enough so that it will not crowd into the strainer at the well bottom and clog it up. The sand also packs so closely around the pipes that wells are driven in and pulled with difficulty. The wind-blown sands are usually not deep, and even where blown into dunes of considerable size they are usually so well drained as to be of little value as water producers.

[a] Leverett, Frank, Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 334-338.

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ROCK FORMATIONS.

GENERAL GEOLOGIC SECTION.

Many wells penetrating deep into the earth pass through rock formations which do not come to the surface in the region. By a careful examination of the records of well borings, and by a comparison of these with the geologic succession in other areas where the deep-lying beds of northern Indiana outcrop at the surface, geologists have been able to determine in some detail the series of rocks which lie below the surface to great depths. Only those formations which have an influence upon the water supply of the region are of interest in this discussion, and only those will be discussed which have been penetrated by the drill. The following table shows in a general way the geologic formations represented, their thickness, general constitution, and value as water carriers:

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Generalized section of the rock formations of northern Indiana.

System.	Series.	Group or formation.	Thickness.	Character.	Water supply.
			Feet.		
Quaternary			0–500	Alluvium, loess, drift, etc.	
Carboniferous	Mississippian	"Knobstone" group	600	Shales with some sandstone and limestone.	Produce little water.
		New Albany shale	50–100	Shales locally bituminous	Very poor water bearers.
Devonian		Sellersburg limestone[a] Jeffersonville limestone[a] Pendleton sandstone	100–350	Bedded limestones, with heavy bedded soft white sandstone (Pendleton sandstone) in certain areas.	Bear considerable waters in areas where they are near the surface.
		Kokomo limestone ("water lime")[b]		Bedded and jointed limestones	Furnish good supplies of water.
Silurian		Niagara formation:[b] Upper division	100–500	Compact, massive, or bedded limestone, in many parts somewhat crystalline, ranging in color from buff to bluish or greenish shades. Immediately below glacial drift in many places in the north and west parts of the area treated.	In many places carries considerable amounts of potable water in joints, bedding planes, and solution passages.
		Lower division ("Clinton")	±50	Brownish or reddish limestone	Poor water bearers.
Ordovician	Cincinnatian	Richmond formation "Lorraine" formation Utica shale	260–1,000	Blue-green shale and blue limestone above and fine-grained brown or black shale below. Does not outcrop in area treated.	Carries very little water. Nowhere known to furnish sufficient for well supply.
		"Trenton" limestone	±500	Massive limestone, in many places dolomitic. Does not outcrop in area treated.	Yields large quantities of salt water.
		Shale (formation undetermined)	25–80		
		St. Peter sandstone	150–250	Porous sandstone. Does not outcrop in area treated.	Carries abundant waters, highly mineralized with salt, sulphur, iron, etc.
		"Lower Magnesian" limestone	±400	Gray sandy dolomitic sandstone. Does not outcrop in area treated.	

[a] The Sellersburg and Jeffersonville limestones together are the "Corniferous" of well drillers.
[b] The name "Niagara," as commonly used by well drillers, includes the Kokomo limestone ("waterlime") and the Niagara formation.

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KOKOMO

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Except the Pleistocene deposits, which for the most part are unconsolidated materials, all the rocks of this region are sedimentary down to the bottom of the deepest well borings. In this area we have three great types of sedimentary deposits with which to deal: (1) Sandstones, which were deposited under water in the zone where wave action was important. In north-central Indiana sandstones are seldom encountered in the sinking of wells, and except in a small area in Hendricks and Boone counties are important as a source of supply only in borings of very great depth. (2) Shales, which were laid down under water; some of them in a zone farther from the shore and in deeper water than the sandstones, and some of them close to shore along low marshy coasts, in protected lagoons or near mouths of streams which carry fine sediments. Shales are encountered by wells in northern Indiana immediately below the glacial deposits, although they are nowhere close to the surface. In the southwest portion of the area, especially in Hendricks, Marion, Boone, Clinton, and Carroll counties, the shales are at many points entered immediately below the till, and at a few places outcrop at the surface along stream cuts. In the remainder of this area, shale is invariably encountered by wells that are sufficiently deep to go through the glacial deposits and the underlying limestone. It is seldom that these shales yield satisfactory supplies of water, and a knowledge of their distribution and characteristics is important to all drillers in order that they may avoid these unproductive deposits. (3) Limestones form the third type of sedimentary rocks. The idea formerly prevailed that the limestones were laid down in very deep waters, far from the shore. Of recent years, however, it has been generally conceded that they were deposited in water less than 100 fathoms deep. This is beyond the shale-forming zone, but is far shallower than the depths formerly believed necessary for the formation of limestone. Indeed, coral limestones are now known to be forming close to the shore. The chief essentials of a limestone-forming area are abundant lime-secreting organisms, comparatively shallow water, and an absence of clastic sediments. No deposits occur in north-central Indiana of such character as to prove beyond doubt that this area was ever covered by deep seas.

ORDOVICIAN SYSTEM.

ST. PETER SANDSTONE.

Description and distribution.—The St. Peter sandstone is known to underlie the "Trenton" limestone, although it has been penetrated but a few times in the northern part of Indiana, in which it nowhere comes to the surface. In areas where it does outcrop, and according to the records of drillings in this and other regions, the formation consists of a massive, porous sandstone, composed of rather firmly

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cemented siliceous sand. Where penetrated by the drill it has been found to be 150 to 224 feet thick. It is underlain by the "Lower Magnesian" limestone.

Doubtless this sandstone underlies the whole of the State, for over a great range of territory it has always been found when the bottom of the "Trenton" has been reached. The "Trenton" is known to lie continuously below this area.

Source and movements of water.—The nearest outcrop of the St. Peter sandstone is in Wisconsin, some two hundred miles from the nearest point in this area. From this outcrop it slopes gently southward. Above the St. Peter there are, in Indiana, thick deposits of impervious shale, which prevent the entrance into the sandstone of any surface waters. Where encountered by borings, the waters of the formation are found to be under considerable artesian pressure, and it is probable that they have traveled slowly through the porous rock from its outcrop in Wisconsin and that the artesian head is transmitted from the same place. The water is included in the pores of the rock as well as in any joints or bedding planes that may exist. The rock is massive, however, and it is not likely that the joints are large or continuous for any great distances, as joints probably develop more freely near the surface than in these formations, which are deeply buried. The movements of the waters, therefore, are doubtless very slow, and the period of time during which the waters have been confined in the rock must have been very long.

Character of the water.—The water from the St. Peter sandstone has not been put to use in the region under discussion. Something is known of its character, however, for at Cincinnati, Ohio, 100 miles southeast of Indianapolis, many wells have penetrated this sandstone, and it is probable that the chemical contents of the water are similar in the two areas. At Cincinnati the water is heavily charged with salt and iron and contains also a noticeable amount of hydrogen sulphide.

"TRENTON" LIMESTONE.

Description and distribution.—The deepest rock formation of this district that has been frequently reached by the drill is called the "Trenton" limestone. Because of the great development of the petroleum and natural-gas industries in northern Indiana many hundreds of wells have been drilled into the "Trenton," in which all the important strikes in oil and gas have been made. The formation is a massive limestone about 500 feet thick. Its actual thickness is seldom recorded, for oil and gas, where found at all, are near the top of the formation, and hence few wells penetrate deeply into it. The top of the "Trenton" lies 850 to 900 feet below the surface in the southeastern counties of this area, the depth gradually increasing to

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the north and west. The "Trenton" underlies the whole of the area covered by this report.

Source, occurrence, and movements of water.—The nearest outcrop of the "Trenton" limestone is in the river valleys in Kentucky, south of Cincinnati. There its top is between 500 and 600 feet above sea level, while in Hancock County, Ind., it is below sea level. This gives the formation a dip to the northwest of 5 or 6 feet per mile. Above it there is a thick series of impervious shales which prevent the entrance of any surface waters. The source, then, of the water found in the "Trenton" is probably the crest of the Cincinnati arch, as the low broad anticline is called which runs south from Ohio and Indiana into Kentucky and which gives the westward dip to the beds on its flank. It may, however, be in the area in northern Illinois and southern Wisconsin, in which these beds come to the surface.

The "Trenton" limestone equivalent which outcrops in Kentucky is a rather solid close-grained rock of small pore space. It is probable that in oil and gas areas the pore space is much greater. It is traversed, however, by extensive systems of joints and by well-defined bedding planes. Both of these sets of openings have in places been enlarged by solution, so that the rock now has certain well-marked circulation channels. The bedding planes, especially, provide open continuous passages for the water, and wells in the "Trenton" rarely fail to strike such channels. It is not surprising, therefore, that the "Trenton" waters, where encountered in north-central Indiana, have lost little of their head and rise in the wells far above the level at which they are reached.

Character of water.—The "Trenton" waters are all highly mineralized and are especially heavy in sodium chloride, some of them being almost saturated with salt. The salt waters are commonly associated with the oil and gas of the "Trenton," and often flood the wells in such quantities that they can not be pumped for oil profitably. As in many other marine formations, the salt was probably derived originally from the evaporation of sea water. In pumping the petroleum the oily salt waters are pumped from the wells and allowed to run over the land and gradually find their way to the streams. In this way the streams, and to a considerable extent the ground waters, have been polluted. Isaiah Bowman[a] has suggested that by direct ditching and by piping these waters to the streams the pollution of the ground waters could be largely avoided. The pollution of the streams seems inevitable as long as the oil and gas wells are producing. When these fail, the streams will have an opportunity to return to their normal state.

[a] Sackett, R. L., and Bowman, Isaiah, The disposal of strawboard and oil-well waste: Water-Supply Paper U. S. Geol. Survey No. 113, 1905.

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Dangers from "Trenton" water.—As stated above, the salt waters of the "Trenton" limestone are often under considerable artesian pressure and in some places will rise in the wells as high as or higher than in the Niagara formation. While oil or gas wells are in use they are cased below the Niagara to keep the water from this and overlying formations out of the well. In this way the "Trenton" and Niagara waters are prevented from mixing. On the failure or exhaustion of deep wells the pipe is often pulled out. A state law has been passed requiring that all "pulled" wells should be tightly plugged below the Niagara. This is to prevent the fresh water from above from getting into the oil or gas bearing rocks, as well as to keep the salty "Trenton" waters out of the Niagara, if the "Trenton" waters are under sufficient pressure to rise to this level. Unfortunately the laws have been evaded and many wells are not properly plugged, so that the salty "Trenton" waters have in places forced their way into the Niagara formation in sufficient quantities to give the Niagara waters a decidedly salty taste. The whole supply of rock waters in certain regions has been imperiled in this way. It is impossible to undo the harm that has already been done, but an appreciation of the serious consequences of a ruined rock water supply should do much to bring about in the future a stringent enforcement of the laws for the proper plugging of all pulled wells.

CINCINNATIAN SERIES.

Description.—Above the "Trenton" there occur three great groups of shales and limestones—the Utica shale below and the "Lorraine" and Richmond formations above. The Utica consists of persistent, close-grained brown or black shales from 50 to 400 feet in thickness, while the "Lorraine" and Richmond formations consist principally of greenish or bluish shales with thin interbedded layers of limestone. The three formations together have ordinarily a thickness between 500 and 700 feet.

Source, occurrence, and movements of water.—The shales which compose the great proportion of these beds are so close-grained as to be practically impervious. The water they contain is included in the microscopic openings between the tiny particles and is held with great tenacity by the shales. Capillary attraction and adhesion to the walls of the pores make these waters almost stationary. It seems probable that some of the water has been in the shales since they were first deposited. Well borings that pass through 500 or 600 feet of these formations get very little water, and what they do get comes largely from the limestone layers.

Character of water.—Few wells in this area find their supply in the shale formations, and there was no opportunity to take samples of unmixed shale waters. In southwestern Ohio and southeastern

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Indiana, where these beds come to the surface, the waters are found to be heavily charged with minerals, containing much more than any of the waters of the surface deposits. This large mineral content results from the lack of free circulation through the shales, the consequent long time during which the contained water remains in contact with them, and the comminuted condition of the particles, a condition that aids in the solution of the minerals. These shales do not outcrop in north-central Indiana, and are not to be considered as a possible source for well supplies there.

SILURIAN SYSTEM.

NIAGARA LIMESTONE.

Definition.—The term "Niagara group" is sometimes used in Indiana to include all rocks of Silurian age. More commonly it is made to include the massive limestones which lie immediately below the drift in much of the northeast part of Indiana. (See Pl. III.) In all the more important oil fields of this area the Niagara is the first rock reached and its thickness is an important consideration with oil and gas well drillers, as it is necessary to case the wells through the limestone to keep out the water. The formation ranges from a thin bed to more than 500 feet thick, varying with the amount of erosion which the surface has suffered. As stated above, the records of well borings often include the Kokomo limestone ("water lime") under the term "Niagara."

Lower division.—The lower part of the Niagara is a series of limestones and shales 50 to 100 feet thick which has been called "Clinton." This lower division nowhere outcrops in north-central Indiana, but nearer the crest of the Cincinnati anticline, in southeastern Indiana and southwestern Ohio, the beds come to the surface. Like the underlying rocks, these beds lie on the flank of the Cincinnati arch and dip to the west and north 5 or 6 feet per mile.

This lower division of the Niagara is inclosed above and below by dense impervious shales, so that there is little opportunity for the beds to receive waters from the adjoining formations. It seems probable from the slope of the beds and the exposed outcrops to the southeast that the waters contained in these rocks have come from the surface outcrops. In the shale beds the waters are held in fine pores, and little movement takes place, as open continuous passages are lacking. The limestones are compact and dense and the joints and bedding planes offer the only channels for circulation. In oil and gas wells the casing is usually continued through the lower division (so-called "Clinton"). The uncased wells which go to these beds receive most of their water from the upper division of the Niagara, and no opportunity was afforded to obtain samples of unmixed waters

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from the lower division. In this area these beds are not important as water producers.

No information was obtained in regard to the character of the waters from the lower division of the Niagara. In southwestern Ohio[a] the waters from this horizon are as soft as any of the ground waters. In that area these rocks are near the surface, and the waters are in continuous circulation and probably do not remain in the rock long enough to dissolve much mineral matter. In north-central Indiana, however, the beds lie much deeper, the water circulation is slower, and the waters are doubtless much more heavily charged with minerals than those in the southwestern Ohio region.

Upper division.—The limestones of the upper division of the Niagara formation are thick and massive, normally 100 to 500 feet thick. They are the oldest rocks which outcrop in the area discussed. They are in many places somewhat crystalline and bluish or buff. Thin beds of shale or "breaks" occur far apart in the limestone, and at its base borings pass through 2 to 40 feet of fine-grained greenish shale.

KOKOMO LIMESTONE ("WATER LIME").

The Kokomo is also a thick, heavy limestone, but is not so massive or so dense in texture as the Niagara and does not show any crystalline structure. Like that of the Niagara its surface is ordinarily covered by a thick coating of till, and the outcrops are limited for the most part to the sides of the deeper valleys. It is well exposed at Kokomo, hence its name.

This limestone is rather flat-lying in the eastern part of north-central Indiana, having a low, uniform dip to the west. It has been greatly disturbed along a northwest-southeast axis, along which the beds are often steeply uptilted and much fractured. This disturbance has been called the Wabash arch.[b] In the north and southwest portions of the area the Kokomo is overlain by later sedimentary beds.

SILURIAN WATER.

Source.—In the areas where the limestones lie immediately below the glacial deposits the limestone waters are largely derived from the till. The actual surface outcrops of the rocks are of small extent and are almost all in the deeper valleys where the waters move outward from the rocks. The main source of the rock waters is therefore in the overlying surface deposits. In the southwest quarter of this area and in its northern portion these limestones dip below

[a] Fuller, M. L., and Clapp, F. G., Underground waters of southwestern Ohio: Water-Supply Paper U. S. Geol. Survey No. 259 (in preparation).

[b] Thompson, Maurice, The Wabash arch: Thirteenth Rept. State Geologist Indiana, 1888, pp. 41–53.

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the later rocks, which contain impervious beds of clay and shale. Under such conditions the limestone waters come from the higher areas, where they are in contact with the permeable water-bearing beds or where the rocks outcrop at the surface and can absorb the rainfall directly.

Occurrence and movements.—The texture of the limestones is dense, and all waters included in the body of the rock are in such fine openings that they are not readily yielded up. The available waters are those which occupy the systems of joints and the bedding planes of the rocks. Such openings are in places widened by solution to form channels several inches or even a few feet in diameter. (See Pl. V, *B*.) The bedding planes especially are utilized by the circulating waters, This is well shown in many stone quarries, where a thin sheet of water constantly flows out from certain bedding planes (Pl. VI, *A*). To have a freely circulating water supply a rock formation must have continuous openings and an outlet for the water at some point lower than the head. With these conditions in a limestone, those openings which are largest and have the most direct course between the source and the outlet have the advantage and receive the most water. With more rapid circulation comes increased solution along the favored channels. In this way complex drainage systems are occasionally developed below the surface. An abandoned channel of this sort is shown in the quarry face in Plate V, *B*. Wells which go through the surface deposits usually find good supplies of water within a few feet of the top of the limestone in the joints and cracks of the rock. Where the limestones are interrupted by shale beds abundant water is usually found just above the impervious shales. Occasionally a drill will break into a solution channel in the rock and drop to the bottom, and most wells which encounter openings of this kind prove to be inexhaustible.

Before the glacial period the surface of the limestones was much broken up and was deeply decayed by weathering. The advancing ice removed much of this broken and loose material, and left many hard, fresh surfaces of rock. In some places, however, the erosion was less severe, or post-glacial weathering has been especially effective, for beneath the till there is a zone of broken and weathered limestone. Into this weathered zone the water penetrates readily, and wells driven through the till into the broken limestone commonly find abundant waters.

Character.—As is to be expected, the limestone waters are invariably hard. The content of lime and magnesium is high and notable amounts of sulphates and chlorides are found in many samples analyzed.

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DEVONIAN SYSTEM.

Description.—The Devonian beds underlie the southwest quarter of this area, but have few outcrops and are not very well known. (See Pl. III.) They are divided into the Pendleton sandstone, the Jeffersonville limestone, the Sellersburg limestone, and the black New Albany shale. The limestones range in thickness from a thin edge at their eastern border to 200 or 300 feet where they have suffered no erosion. The outcrops are usually covered with a heavy deposit of glacial till. The sandstone, the type locality of which is in Madison County, varies in thickness up to 20 feet.

The New Albany shale is a close grained black or bluish shale about 100 feet thick, which outcrops in a narrow strip between the Devonian limestones and the Mississippian shales. (See Pl. III.) It is covered by a thick till sheet and few wells go into it.

The Devonian beds occur also in the northern portion of the area but are so deeply covered by surface deposits that their distribution is not known.

Source, occurrence, and movements of water.—The limestones have few surface outcrops and must receive their waters at their contact with the overlying till. No water could enter them from above in their deeper portions, where they are covered by the impervious New Albany shale.

The New Albany shale is so close grained that it contains little water and retains what it has. Very little additional water is needed to keep up the supply. The water is nearly stationary.

The limestones contain some water in minute pores, but their available supply is in the joints, bedding planes, and solution passages. At Indianapolis many wells are supplied by this limestone, and in a number of them the drill has broken into well-defined channels. Many of the wells give a large yield, but the demand upon the rock waters in this city is greater than the supply and the head has been gradually becoming lower for a number of years.

CARBONIFEROUS SYSTEM (MISSISSIPPIAN SERIES).

"KNOBSTONE" GROUP.

Description.—In the extreme southwest corner of the area covered by this report the rock formation nearest the surface is the "Knobstone" group, which lies immediately below the glacial deposits in parts of Marion, Hendricks, Boone, and Clinton counties. (See Pl. III.)

The "Knobstone" group consists of an alternating series of sandstones and shales, the sandstones gaining in relative importance toward the top of the group. The "Knobstone" at its greatest development has a thickness of about 600 feet. The beds are little disturbed and dip to the southwest as an inclined plane of low slope.

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Source, occurrence, and movements of water.—The outcrops of the "Knobstone" everywhere in this area are drift covered, though they are the youngest rocks of north-central Indiana. The numerous shale beds which are distributed through the group effectively prevent the vertical circulation of waters. The rock waters therefore must be derived from the drift at the point of contact with the porous beds of the underlying formations. The shale beds are so close grained that the circulation of water in them is inconsiderable. In the sandstones the circulation is more free but is confined by the shales to single beds.

In the area of the "Knobstone" outcrops most of the wells are supplied by waters from the overlying surface deposits. The few wells which enter the rock find fair supplies in the sandstones, but no water in the shales. In the sandstone the waters are commonly found in crevices in the rock and in the pores.

GROUND WATER.

SOURCES.

PREVAILING IDEAS.

An idea which seems to have found rather wide credence in States bordering the Great Lakes is that the flowing wells are in some way connected with these lakes and that the head of the wells is maintained by them. Of the area here discussed only a narrow strip along the Wabash River in the neighborhood of Delphi has a lower elevation than 581 feet, the level of Lake Michigan, and Lake Erie is still lower. Delphi is about 75 miles from Lake Michigan. A large surface stream from Lake Michigan to Delphi would flow sluggishly, while the friction of underground waters in even the most porous of rocks would so reduce this head in 75 miles that a flow would be out of the question. Furthermore, the mouths of nearly all the flowing wells in the area are far above the level of Lake Michigan.

As for the shallower wells which do not enter rock at all, the source of head is as a rule local and is generally not more than a few miles from the well and commonly only a few hundred feet. This will be readily understood from the fact that most of these wells end in beds of gravel interbedded with glacial clays. These gravel beds are commonly of slight extent and vary greatly in thickness even in short distances. The source of head in such gravel beds must be within the limits of the open bed, which is usually only a few square miles in area.

Another common expression is that the drill penetrated a "lake" of water. Most such "lakes" of water are beds of porous gravel through which the water can enter the well as rapidly as it is pumped out. Actual cavities filled with water are locally found in limestones, but

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are not generally encountered in the areas which were glaciated. The erosive action of the ice wore away the upper portion of the limestone below the zone in which such caverns are likely to occur, and the period of time since the glacial epoch has been too short for the formation of very extensive solution channels.

Another common and perfectly natural idea is that the wells in the lowlands near rivers or lakes are supplied by these bodies of water. In some instances this is actually so, but the water supplied to most wells is drawn from the store of ground water and not from the surface waters. This will be understood by reference to figure 2; *W* is a well situated along a river flat; *G–G′* is the surface of the water table. The normal movements of the underground water are in the direction of the arrows. As long as the amount of water pumped from well *W* is not greater than can be supplied from the ground water without lowering it below the level of the river bank, or the stream does not rise more suddenly than the water table of its banks, the well will receive little water from the river. This has been definitely determined by the analyses of the waters from both sources. If the well is pumped enough to lower the water level the water from the river will flow into the well, which will yield a mixture of ground water and river water. The same conditions obtain if the well is located near a lake or a marsh.

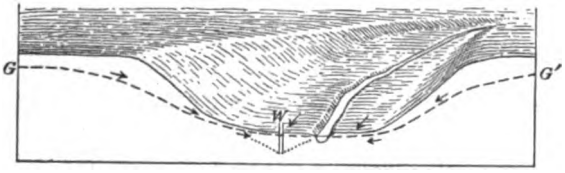

FIGURE 2.—Relations of flood-plain wells to the neighboring stream.

ACTUAL CONDITIONS.

Ground water is a term which has been applied to water, from whatever source, which is below the earth's surface. With little exception this water has all been precipitated upon the surface of the earth and absorbed through the various kinds of pores, cracks, and open spaces. As shown by the preceding paragraph, it is evident that the ground-water supply receives slight contributions or none from the established surface streams or lakes. On the contrary, the streams owe their permanence to a perpetual supply which they receive from the body of ground water. Without this ground-water supply most of the shorter streams would speedily drain their basins after each shower and would then remain dry until the next rain. As it is, numberless streams having very small drainage basins flow all or almost all of the year and fail, if at all, only when the ground-water level has been lowered below their beds by a season of great evaporation with little rainfall.

For the source of the great body of ground water we must therefore look to the precipitation which is absorbed by the earth and

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which percolates below the surface into the openings of the underlying materials. The total precipitation in any region can be divided into three parts: (1) That which is evaporated directly; (2) that which runs off the surface at once; (3) that which is absorbed and becomes ground water. The proportions of these three divisions vary greatly under different conditions of topography, soils, climate, and precipitation. With given conditions of precipitation, climate, and soil, however, the great factor in determining the proportions of the above three classes, is the topography, or configuration of the earth's surface. It is clear that in areas of steep slopes and well-established drainage the proportion of run-off will be large at the expense both of absorption and evaporation. In regions of slight relief and of few and sluggish streams the proportion of run-off will diminish and that of absorption and evaporation increase. As stated above, these proportions are vitally influenced by the character of the soil and the climate and the rate and character of the precipitation. As the area under consideration is for the most part a nearly level plateau of moderate elevation, without many deep valleys, the absorption is relatively large and all of this absorbed water goes to swell the body of ground water on which the wells depend.

MOVEMENTS.

IN THE SURFACE ZONE.

The manner in which the water is absorbed and stored in the earth varies greatly with the materials. In the unconsolidated surface materials which cover almost the entire area there is a nearly complete absence of well-defined continuous openings or passages. In these materials the water is absorbed into the pores between the particles by gravity and by capillary action and gradually moves downward to the water table, where it is stored in similar openings. In loose material the amount of water which can be held and the rapidity of movement possible for the waters are determined by the character of the materials and the size and continuity of the openings. In fine-grained clays the amount of water which can be stored may be large, but the movements of the water are necessarily extremely slow. In coarse, uniform gravel, on the contrary, the storage capacity for water is great and the movements of water may be rapid.

The waters near the surface of the water table move much more rapidly than those more deeply situated. The surface of the water table fluctuates somewhat with the seasons, but these movements decrease rapidly downward except in rocks with well-defined and continuous water channels. Toward the surface of the water table the movements of the underground waters have commonly a

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close relation to the movements of the surface waters. This is especially true in this region, where the water table is ordinarily in the unconsolidated, structureless glacial till. This relation is shown by the arrows in figure 2. Figure 3 shows a different set of conditions. If the rock surface R–R' is considered to represent the surface of the earth the movements of the ground waters would be along the

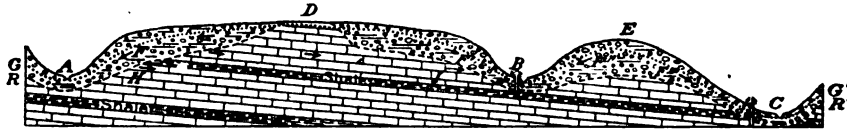

FIGURE 3.—Influence of surface slopes and of structure on movements of underground waters. Dotted line G–G' is the water table. Broken line R–R' is the rock surface. The water movements in this rock are along the bedding planes. The material above the rock is a rather impervious pebbly clay. The arrows indicate the direction of the underground water movements. D is a plateau with equal slopes toward A and B. On the slope toward B both the clay and rock waters move toward B. Only the clay waters move toward A, the rock waters moving in the opposite direction. The waters at H and I, independent of the surface topography, move past valley B to valley C. The conditions are favorable for artesian flows from rock wells at B and C if the surface deposits are impervious.

bedding planes in disregard of the surface slopes. If, however, the rock surface is covered to some depth with glacial drift, the upper ground waters will move in the same direction as the surface drainage, but the movements of deeper waters will be controlled by the structure of the rock.

IN THE DEEPER ZONES.

The movements of the deeper underground waters are determined by an entirely different set of factors from those which regulate the movements near the surface. The most important of these factors are the character and the structure of the saturated materials and the opportunity for escape of the waters. In very deep waters changes of temperature may be the controlling influence in the circulation, but such deep waters are reached by few wells and are therefore outside the province of this paper.

The older consolidated rocks which lie under the surface deposits contain water in their openings down to the bottom of the deepest borings. These rocks all contain a considerable amount of pore space, usually less than the unconsolidated materials. These pores contain some water, but the movements of the water in the pores is usually too slow to furnish wells with suitable supplies. Parallel to the beds of many rocks there are sheetlike openings called bedding planes. Many of the rocks, though they may be very dense in texture, have continuous openings or cracks which cross the bedding planes. Such cracks are called joints. From the open and continuous nature of the joints and bedding planes they form the most natural and convenient channels for the movements of underground waters and for their storage. In many places abundant supplies of

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water are found in deep-lying limestones or sandstones, which are separated from the surface of the earth by beds of impervious shales. In such places we must look to some distant point for the source of the waters—to a place where the water-bearing formation comes to the surface or where at least the overlying impervious formation is lacking. This point may be scores or even hundreds of miles from the point where the water is reached by the wells, and the water has traveled the whole distance through the joints, bedding planes, and pores of the rock. This is true of a few wells which have found their water supply in the porous St. Peter sandstone or the underlying sandstones. The nearest point of outcrop of these formations is far up in Wisconsin and the waters must have come at least that distance.

Although we have certain rock waters whose source is distant, it does not necessarily follow that the source of all rock waters is far from the point at which they are reached by wells. On the contrary, many rock waters are supplied by the precipitation in the immediate neighborhood of the wells from which the water is drawn. This may be true even though the rock does not outcrop at the surface. If the rock is overlain by porous gravel or gravelly clay the water may penetrate through this into the rock and move downward into still deeper rocks if there is no intervening impervious bed. There can be no question that in this area much of the rock water is in this way supplied by the overlying drift to the rock. The "Niagara" limestone, which lies immediately below the drift in much of the east and central parts of this area (see Pl. III), yields abundant waters to a large number of wells, though it actually outcrops at the surface over a very small area. The waters are fed to the limestone by the drift above, and many flowing wells along the bottom lands have tapped this source of supply. It is impossible to estimate accurately the time which may have been required by certain deep waters to move from their sources to the point where the water now issues from the wells. We know only that even with the most favorable conditions—an open, porous, or much fractured and jointed rock, with a strong head of water and a free outlet below—the length of time the water must have required to travel, say, 100 miles is necessarily great. With the actual conditions in the St. Peter sandstone—a rather porous but not much fractured rock, with considerable head but no adequate outlet below—the period of time the water has been in the rock is without doubt enormous. It even seems reasonable to suppose that in some of the deep-lying, impervious shales a part of the water now found may possibly have been there since the sediments were first laid down.

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OCCURRENCE.

RELATION TO TOPOGRAPHY.

Below the earth's surface a level may always be reached at which the materials are saturated with water. This saturation may extend downward indefinitely, or only to some impervious layer. In either case the upper surface of the saturated zone is known as the water table. There is an intimate relation between this water table and the surface topography, and while the water table usually follows, in a general way, the slopes of the surface, it is much less irregular and of milder relief. Thus, on hilltops there is a ready drainage on all sides, and the waters falling on the surface flow off rapidly as surface waters, or entering the soil become ground waters and escape more slowly by percolation. The level of the water table is, therefore, farther from the surface on the hilltops than in the lowlands, where there is a less ready escape for the ground water and where the surface slopes are less conducive to rapid run-off. Figure 4 indicates the relation of the ground-water table to the surface slopes.

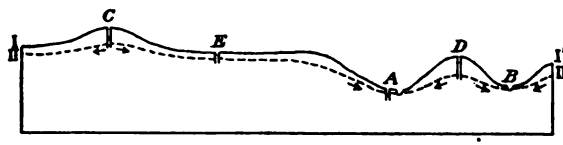

FIGURE 4.—Diagram showing relation of the water table, II-II' to the surface topography I-I'. The most favorable locations for wells are at *E*, *A*, and *B* It should be noted that well *C*, though on much higher ground than *D*, finds water nearer the surface. The arrows indicate the direction of the underground water movements.

These relations are important only in their influence on the waters near the surface of the water table. The deeper waters are affected by the variations of the water table only as these variations either increase or decrease the hydrostatic pressure in their own areas.

RELATION TO STRUCTURE.

Rock waters have certain characteristic methods of occurrence and the manner of occurrence in each type of rock is more or less constant. In general, rock waters are contained in three varieties of openings—(1) pores, (2) bedding planes, and (3) joints. Any one or all of these classes of openings may become enlarged by solution to form continuous channels of considerable extent.

Pores.—Pores are the minute openings between the imperfectly fitting particles of which a rock is composed. In many rocks the total amount of water contained in the pores is greater than that contained in all the other openings. The pore spaces, however, have a remarkable capacity for holding their water and do not commonly yield much to wells.

Bedding planes.—Bedding planes are the sheet-like partings between beds of rock that are different in texture or arrangement of materials. Bedding planes may be very inconspicuous in fresh rocks,

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but become prominent as soon as the rock is attacked by solution or weathering. As a result of the slow percolation of the water along the bedding planes the openings may be enlarged by solution until passages of considerable size are formed, especially in limestones and in calcareous shales. In many sedimentary rocks the bedding planes offer the readiest means of circulation to the rock waters and therefore furnish the best supplies to wells that penetrate them.

Joints.—All hard, brittle rocks are traversed by sets of cracks formed to relieve stresses which have at some time been set up in the rocks. In sedimentary rocks some of these planes of fracture coincide with the bedding planes and can not be distinguished from them. Other sets of cracks may intersect the bedding planes, and these, which in this area are usually nearly vertical, are called joints. In many rocks the joints offer the easiest means of passage for underground waters, and some of them are dissolved out to form well-defined underground stream courses. Such solution passages have a tendency to form at the intersection of a joint with a bedding plane. It is a common occurrence with drillers for the drill to "drop" several inches, or even a foot or two, into one of these solution cavities. An abundant supply of water is generally found in these openings.

RELATION TO TYPE OF MATERIAL.

UNCONSOLIDATED DEPOSITS.

Since the unconsolidated materials contain no definite partings corresponding with the joints and bedding planes of the hard rocks, the waters are all contained in the pores. The pores range in size from the large openings in coarse gravels to the capillary and subcapillary openings in the dense clayey till. As the amount of water available for wells depends for the most part upon the size and continuity of the pores, the texture of the material determines to a large degree the value of any bed as a water producer. The characteristic features of the various types of unconsolidated materials and their capacity to furnish wells with water have already been discussed.

CONSOLIDATED DEPOSITS.

Sandstones.—Most sandstones yield considerable water from their pores as well as from their joints and bedding planes, and where sandstones are found within a reasonable distance of the surface they generally offer a good source for well supplies. In north-central Indiana, however, the only notable sandstone deposit is the St. Peter, which is a good water producer where accessible but which in this region lies so deep that it has been reached by the drill only a few times. Some wells in western Boone and Hendricks counties are supplied by waters from sandstones of the "Knobstone" group.

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Shales.—The shales of this area are fine-grained rocks which are not much indurated. On account of their softness they are rather plastic, and the stresses which have fractured the harder limestones and sandstones have not had this effect on the shales. The impervious character of these shales is unfavorable to the circulation of underground waters, and not many solution channels are developed in them. Although the pores occupy relatively great space, they are too fine to permit the water to escape readily. Hence few wells find satisfactory supplies in the shale beds.

Limestones.—Although limestones contain a relatively small amount of pore space, they afford the best source of rock-water supply in this region because of their solubility and the consequent fact that the percolating waters have so widened and enlarged the joints and bedding planes as to convert them into open channels, through which the water circulates freely when once it has penetrated them. Thousands of wells have been drilled into the Silurian limestones ("Niagara" of well drillers), and very few of them have failed to find sufficient water for domestic use. In many places large quantities of water are obtained from this limestone for manufacturing purposes and for city supplies.

VOLUME.

As already stated, the volume of underground water depends in a measure upon the surface configuration of the region. No matter how great the precipitation or how great a proportion of this water enters the ground, the volume of ground water will not be large unless the topography of the region and the character of the materials are favorable for holding it. If there is a ready opportunity for the waters to escape to the surface again, the water table will be lowered as fast as it is augmented from above. For this reason the water table in a region of deep valleys and narrow divides will, on the average, be much farther from the surface than in another area of similar climate and materials where the general level is little dissected by valleys. The greater part of northern Indiana consists of till plains of slight relief, and over most of this area the water table stands near the surface.

By available water is meant that water in a formation which is free to enter a well sunk near it. This definition excludes a large part of the water in very fine-grained materials, such as shales and clays, in which the pores are so small that their capillary attraction and their lack of continuity prevent the escape of water. In the coarser sands and gravels the pores and openings are large and relatively more continuous, and nearly all of the water in such coarser deposits is available. The amount of available water, therefore, depends more upon the texture of the material than on the total amount of

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pore space. A clay may contain 25 to 35 per cent of pore space, but may yield very little water to wells; a coarser sand, with perhaps less pore space, may yield the greater part of its water to wells. Sandstones, if porous, will give up much of their content of water. In limestones the only water available is that which lies in the well-defined joints, bedding planes, and solution channels. The water contained in the body of the limestone is not available.

MINERAL MATTER IN SOLUTION.

The amount and character of the mineral matter which underground waters carry depend upon a complex set of conditions. Two factors, however, deserve particular discussion because of their relative importance. The amount of mineral matter which a ground water carries depends (1) on the solubility of the materials through which the waters have passed and (2) on the length of time during which the water has remained in contact with these materials. The solubility of the materials encountered is, perhaps, the most important single factor. Waters passing through salt beds, for example, might in a short time become very saline, even to the point of saturation. Other waters might remain in pure siliceous sandstones or quartzites for ages without acquiring much silica. With regard to lime, magnesium, and similar substances with which waters are rarely saturated, it is largely the time during which the waters are in contact with these substances that determines the amounts dissolved, though temperature, pressure, and the chemical action of the substances in solution upon those encountered are important factors. The relations between the character of the rock formations and the quality of the waters from them are discussed in the chapter on the chemical character of the waters by R. B. Dole (pp. 230–267).

SPRINGS.

DRIFT SPRINGS.

As a result of the coating of glacial deposits which almost completely mantles this region, most of the springs that occur throughout the area necessarily emerge from the glacial drift. All springs that come from these glacial deposits are classified as drift springs. It is possible that in some springs the waters are supplied from channels in the rock below, but when this could not be determined, the waters were classed as coming from the materials out of which they emerge.

For the occurrence of well-defined springs it is necessary that the water table should come to the surface and that the surrounding water-bearing materials should allow a ready circulation of the waters. If the materials are close grained and the circulation is sluggish, the

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water will emerge as "seeps" and not as well-defined springs. In the drift favorable conditions most commonly occur in the morainic areas where there is considerable surface relief, and where there are many beds of gravel interbedded with clayey drift. Figure 5 shows two conditions in a moraine which would give springs. Spring No. 1 comes from a gravel lens in the bowlder clay. This lens has no surface outcrop above, but receives its water slowly from the overlying drift. As the water can escape most readily by following the open gravel bed to its outcrop, spring No. 1 is formed. Spring No. 2 emerges from the contact of the gravel capping on a hilltop with the underlying more impervious bowlder clay. The water absorbed at the surface passes down through the gravel to the clay and follows the contact to its outcrop on the hillside, where spring No. 2 is formed.

FIGURE 5.—Conditions producing springs in glacial drift.

ROCK SPRINGS.

The rock outcrops in this area are almost all located along the sides of the deeper valleys, and it is along these valley-side outcrops that most of the rock springs are found. The springs issue from just above some impervious bed in the limestone, or from some solution channel or prominent bedding plane. In some places, especially in fresh quarry exposures, there are flows of water from all the more conspicuous bedding planes. (See Pl. VI, *A*.) Figure 6 illustrates the conditions favorable for rock springs along the valleys. Bed No. 1 is till; No. 2 is a fractured and somewhat weathered limestone overlying an impervious shale, No. 3. Springs will issue at *A* and *A'*. Beds Nos. 4, 5, and 6 are limestone. Between beds 4 and 5 there is the opening of a large solution passage, and a large spring discharges at *B'*.

In unglaciated limestone regions the upper portion of the limestone is in many places so honeycombed by solution caverns and passages that surface streams of large volume may disappear into these underground channels, to reappear at a distance as large springs. In northern Indiana there may once have been many such underground streams; but the erosion of the glaciers removed the more open upper surface of the limestone, and the larger underground channels have not yet

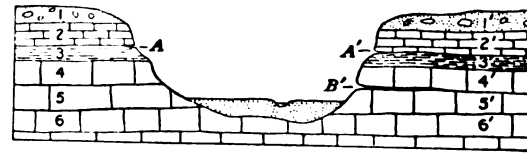

FIGURE 6.—Conditions producing springs in rocks.

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been reestablished. For these reasons the rock springs are all rather small as compared with those of unglaciated areas.

W. S. Blatchley has published a report on the mineral waters of Indiana,[a] which includes descriptions and analyses of several springs and mineral wells in north-central Indiana.

WELLS.

METHODS OF CONSTRUCTION.

OPEN WELLS.

Description.—Open wells are commonly 3 or 4 feet in diameter and 15 to 30 feet deep, though a number ranging from 50 to 70 feet were found. They are ordinarily walled up with brick or broken rock, without cement or mortar, so that water can enter from any bed through which the well passes. The depth is determined by the abundance of the water encountered. The deepening is usually continued until the water comes in so rapidly that digging is impossible, when the wall is laid. Most well diggers can tell of experiences with wells in which little water was found until suddenly a porous gravel or a passage in the clay was opened from which the water poured so rapidly that the well could not be walled up. It may be necessary to fill such a well with broken rock for several feet before a wall can be started.

Disadvantages.—Open wells often "go dry" in dry seasons, when the need for water is greatest. This is always possible unless the well bottom is below the permanent water table and in a material which yields a continual and readily available supply. Open wells are subject to contamination, both from above and below ground. The only protection usually afforded to wells above is a board platform. Constant wetting and drying usually causes the boards to warp and shrink, leaving cracks between them. The drippings from the spout upon the well top carry down into the well whatever accumulations there are of dirt from shoes, domestic fowls, or other sources. In the country the farm well is the congregating place for domestic animals. The waste water allowed to run over the ground near by carries down with it any soluble material it may find and reenters the well.

Many open wells are polluted from below the surface. The liquid materials from cesspools and the drainage from manure piles, chicken yards, and manured fields enters the ground and becomes part of the body of underground water upon which the wells depend. In open wells this polluted water from above can enter at the top of the water table as well as the purer water below.

[a] Blatchley, W. S., Mineral waters of Indiana: Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1901. Halsall Spring, near Maxwell, Hancock County, p. 57; Cartersburg Mineral Spring, near Cartersburg, Hendricks County, p. 60; Winona Mineral Springs, at Winona Lake, Kosciusko County, p. 69.

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BORED WELLS.

Bored wells are by no means rare, but are far less common than either of the other two types. They are bored with an auger and lined with tile or wood. The joints in some such wells are filled with cement, but are likely to leak, as the cement must be put in before the tile is lowered into the boring. They have been found to be less satisfactory than the driven or drilled wells.

DRIVEN AND DRILLED WELLS.

General description.—Up to the last decade the dug or open well was the type most commonly used for domestic purposes, both in towns and rural districts. With the ditching of low or marshy tracts and the decrease in the acreage of timber lands, the water table has gradually become lower. Within the memory of many older residents the water table in certain areas has been lowered from 5 or 6 feet below the surface to 15 or 20 feet below. In these areas dug wells which for years furnished an unfailing supply of water are now dry for the greater part of the year. A more general knowledge of the proper sanitary conditions for wells has also led to the abandonment of many dug wells. To replace the unsatisfactory open wells, thousands of driven and drilled wells have been put in and a large number of men now make a profession of drilling or driving them. Throughout the area as a whole the drilled and driven wells now considerably outnumber the open wells. They are much smaller than the open wells and range in diameter from 1¼ to 8, 10, or even 12 inches. At least nine-tenths of them are 2 inches or less in diameter. The wells consist of a tightly jointed iron pipe sunk into the earth to a water-bearing bed. If this bed is a loose material, such as sand or gravel, a strainer or screen is placed over the lower end of the pipe to keep the gravel or sand out of the well. If the well is in rock the pipe is left uncovered below.

Driven wells.—Driven wells are those which are made by driving a pipe into the loose surface deposits without first making a hole for the pipe to go into. They can be sunk only in unconsolidated materials and never go into rock. To make the pipe drive more easily and to keep it from filling up with loose material, a conical brass point, full of fine perforations, is fastened to the lower end. There are many methods of driving the pipe, varying from the wooden hand maul to a steam-driven trip hammer, the method used depending on the depth and character of material to be penetrated.

The driven wells are especially adapted to areas of valley alluvium, of gravelly outwash, or of till or morainic drift in which there are gravelly or sandy layers. Many can be driven in a few hours and at very little expense. No pollution can get into the well from above and water is drawn only from the deepest and usually the safest

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water bed. Many driven wells show a decrease in supply after a few years' use, due to corrosion or clogging of the screen. The pipe can usually be pulled at small expense, the screen cleaned or replaced, and the well redriven, with a renewal of the original supply.

Drilled wells.—Drilled wells are made by first drilling a hole and then driving a pipe into it. The hole is commonly made with a wedge-shaped drill driven by a steam engine. Plate V, *A*, shows a common type of well rig used in this area. Under the classification of drilled wells comes a type of well made by forcing water or steam under high pressure through a pipe into the loose surface deposits, and forcing the pipe down constantly as the materials below are washed out of the top with the water, or forced out by the steam. This process is often called jetting, and sometimes the wells are called driven wells. Still another process is a combination of the jet and the drill. The drill, with a small opening on either side just above the cutting edge, is jointed to an iron pipe. Through this pipe water is constantly forced into the well, and the materials loosened by the drill and the streams of water are carried out of the well top by the water.

Drilled wells are the prevailing type in areas where the rock waters are the chief source of supply. On the till plains the tough clays in some places prevent the driving of deep wells and there drilled wells are more common. The bowlders embedded in the till will stop a driven well, but the drill can cut through them. In any material in which it is necessary to go to a depth of 100 feet or more the wells are usually drilled.

Drilled wells that end in unconsolidated materials are provided with a screen, let down on the inside of the casing after the well is completed. A common method is to lower a screen, 3 or 4 feet long, to the well bottom and then to pull back the casing far enough to expose the screen.

COMBINATION WELLS.

A combination of the dug and driven or of the dug and drilled wells is very common. Many dug wells that fail in dry seasons, or for other reasons have proved unsatisfactory, are deepened by driving or drilling. In such wells care should be taken to continue the casing up through the well to the surface to prevent the dug-well waters from entering the driven or drilled wells. Wells drilled into the bottom of dug wells are likely to receive some water from the old well, unless the casing fits the hole very snugly. It is recommended that when these combination wells are made the dug portion of the well should be filled up with clean clay. This will prevent any possible pollution of the deeper waters by those from the old well.

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FLOWING WELLS.

ESSENTIAL CONDITIONS.

In many areas in north-central Indiana the waters in certain be are under sufficient artesian pressure to cause them to flow at t surface without pumping. These flowing wells are much prized, they furnish a continual supply of fresh water for city, domestic, farm uses. Plate IV shows the areas in which flowing wells ha been obtained.

The conditions necessary for artesian flow were defined a numb of years ago by T. C. Chamberlin.[a] These conditions apply both the flows from rock wells and to those from surface deposits, and a as follows:

1. A pervious stratum to permit the entrance and the passage of water.
2. A water-tight bed below to prevent the escape of the water downward.
3. A like impervious bed above to prevent the escape upward, for the water, bei under pressure from the fountain head, would otherwise find relief in that directio
4. An inclination of these beds, so that the edge at which the waters enter will higher than the surface at the well.
5. A suitable exposure of the edge of the porous stratum, so that it may take in sufficient supply of water.
6. An adequate rainfall to furnish this supply.
7. An absence of any escape for the water at a lower level than the surface of t well.

A recent paper of M. L. Fuller[b] has added a number of modific tions to the requisite conditions of artesian flow as outlined b Chamberlin.

In many wells which do not flow the water rises under artesia pressure, but not to the top. In these the conditions are the sam as for flowing wells, except that the pressure is not adequa to raise the water to the surface. In both kinds the waters a under artesian pressure, but in this report only those areas in whic actual flowing wells are found are mapped as artesian areas. In th region treated in this report there are two distinct types of flowin wells—(*a*) those whose water is derived from surface deposits, an (*b*) those whose water is derived from rock.

IN SURFACE DEPOSITS.

Most flowing wells in surface deposits reach their supply in grav beds in the moraines, in the till, or in fluvioglacial outwash plain below the moraines. In figure 7, *A* is a well sunk to a lens of grav in moraine. The fountain head of the water is at the outcrop this gravel bed higher up on the moraine. The area in which flowin

[a] Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 18 pp. 125-173.

[b] Summary of the controlling factors of artesian flows: Bull. U. S. Geol. Survey No. 319, 1908.

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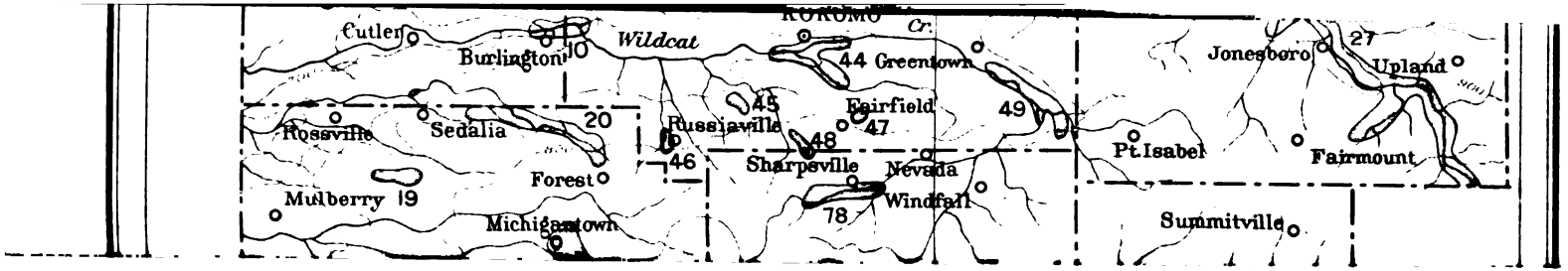

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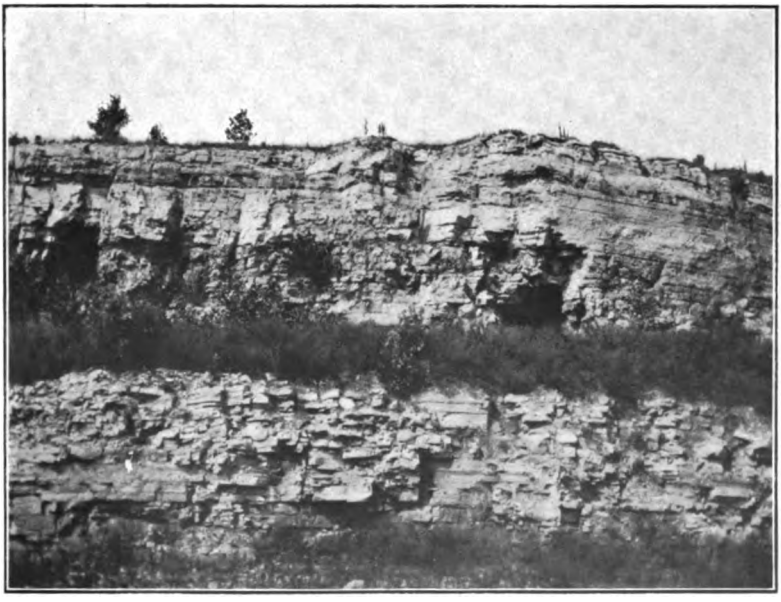
A. COMMON TYPE OF WELL-DRILLING RIG.



B. SOLUTION CHANNELS IN NIAGARA LIMESTONE.

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wells might be obtained is very small. In the well at *C* the water would rise under artesian pressure almost to the surface, but would

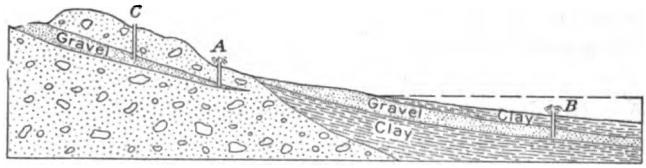

FIGURE 7.—Conditions that yield artesian flows in moraines and in outwash gravels.

not flow. Flowing well *B*, on the outwash plain, taps a gravel bed between two impervious clay beds. The head for the water comes

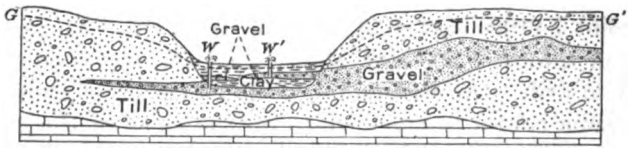

FIGURE 8.—Conditions of flow in alluvial gravels with head supplied from the drift gravels. Artesian waters are found in alluvial gravel by well *W'*, and the head is supplied by an irregular gravel bed in the drift. Flows may also be obtained by wells at *W* from the drift gravels. *G-G'*, water table.

from the gravel outcrop at the base of the moraine. Wells anywhere on the plain around *B* would get flowing water.

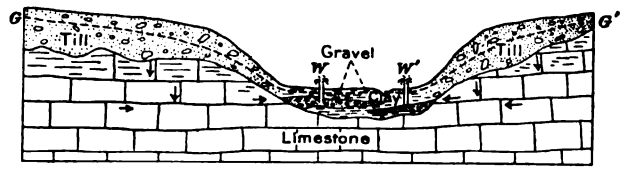

FIGURE 9.—Conditions of flow in alluvial gravels with head supplied from the limestone. *G-G'*, water table. Water for wells *W*, *W'* is supplied to the gravel by the limestone, which receives the water from the till.

Figure 8 shows conditions in which wells in valley alluvium may find flowing waters, the head being supplied from the surface deposits; in figure 9 the head of water is supplied from the limestone.

IN ROCK.

In the part of this area which lies south of Wabash River there are in every county numerous wells that penetrate rock. North of

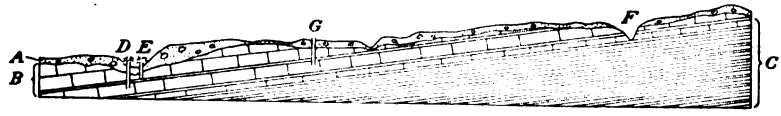

FIGURE 10.—Conditions that yield artesian flows in rocks.

the Wabash the surface deposits are very deep and few wells go through them. In all parts of the area, however, the wells that

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go deep into the Silurian limestones ("Niagara") encounter water under artesian pressure. This pressure is generally not sufficient to give flows in the uplands, but in the river valleys many deep wells get flowing waters from these rocks. The question naturally arises as to the source of the waters. Most writers in discussing flows from rock ascribe the source of head to some higher outcrop of the water-bearing formation at a point where it can receive the rainfall directly or from pervious overlying beds. In applying such an interpretation to the flows from rock in parts of this area grave difficulties are encountered, and the ordinary hypothesis seems to fail. The opportunities for water to enter the "Niagara" limestone at distant and higher outcrops are outlined below.

At a point 7 miles east of Richmond, Ind., the "Niagara" has an elevation of almost 1,200 feet above sea level, but is covered by 25 to 50 feet of drift. At Richmond, at an elevation of about 950 feet, this limestone comes to the surface on the sides of the canyon-like valley of the East Fork of Whitewater River, but the cliff-like outcrops are unfavorably situated for absorbing large quantities of surface waters. Between this high outcrop and the flowing wells above mentioned there is a distance of about 50 miles, throughout the whole of which distance the "Niagara" lies immediately below the drift. The drift itself varies so in texture that it can hardly be supposed to form an impervious covering for the limestone for so long a distance.

The Richmond area lies on the flank of the Cincinnati arch, from which the rocks all dip to the west. It may be that waters entering near the base of the Niagara at Richmond and flowing westward along the gently dipping bedding planes pass beneath impervious shale beds and accumulate enough head to supply flowing wells in the lowlands. The possibilities of flows from this source are illustrated in figure 10. *A* is the covering of glacial deposits; *B* is the "Niagara" limestone with its interbedded shales. The surface waters, entering the base of the limestone at *F*, pass downward under an impervious shale bed. A well at *G* will find water under artesian pressure, but owing to loss of head from friction the well will not flow. Well *D*, in the lowlands, gets flowing water. At well *E* the waters have entered the limestone through the thin drift toward *G*, but the thick drift of the valley has prevented their escape, and a flow is obtained in the upper part of the limestone. The flows from the "Niagara" are all found in the deeper valleys or in depressions somewhat below the level reached by the surrounding surface deposits, and the head is generally not more than a few feet above the surface. In certain wells the flowing waters are procured from below impervious shale beds, or "breaks" in the limestone, and in these wells the head of the waters is probably transmitted from a distance. (See

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fig. 10.) In most wells, however, the flows are from the upper part of the limestone, and such a distant source for the waters seems improbable.

The head for most of the flows from rock seems to be furnished by the heavy overlying mantle of glacial drift. In the drift the water table stands high above the valley bottoms, and even where the transmission of water from the drift to the rock is slow a constant pressure may be maintained in the rock waters if there is no ready escape for them. Wells tapping such a rock supply may obtain flows if they are situated in the deeper valleys or at the foot of the drift hills. Figure 11 shows the conditions for flow in such an area.

Most of the deep wells which obtain flowing waters from great depths were drilled originally for gas or oil. In these wells an outer casing or drive pipe, usually 8 inches in diameter, is driven down to the surface of the rock, and within this pipe a 6-inch casing is carried down to the bottom of the "Niagara" to shut out the water from that rock. The flowing waters, if such are encountered in the limestone, come up between the drive pipe and the casing. When no oil or gas

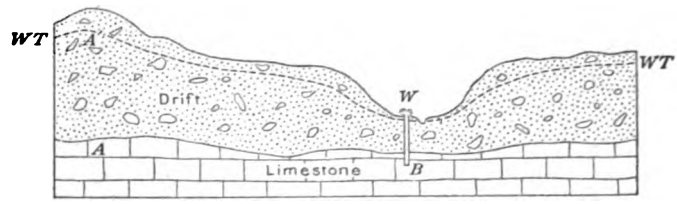

FIGURE 11.—Conditions for artesian flows in limestone, with head supplied by the overlying drift. *WT* is the water table. The water percolates slowly into the limestone from the drift and at *A* is under pressure from the hydrostatic column between *A* and *A'*. The pressure is transmitted through the open bedding planes and joints to *B*, and well *W* obtains an artesian flow.

is found or when the supplies fail the casing and drive pipes are as a rule pulled. Pulled wells are required by state laws to be plugged below the limestone to prevent the interchange of waters between the "Trenton" and the "Niagara." In many flowing wells the drive pipe is left in and the well used to supply water.

LOCATION OF FLOWING WELLS.

It is often difficult to predict just where artesian wells can be had, and no general statement will cover all parts of this area. It can only be said that wells in depressions or at the base of high moraines are more likely to obtain flows than those on higher ground.

The areas in which flowing wells from rock are obtainable are usually long, narrow belts occupying the bottoms of the larger valleys. Most flowing wells from surface deposits are due to local conditions, which are confined to small areas. The map (Pl. IV) gives the location and outlines of the areas in which flowing wells have been obtained. Future borings will doubtless modify the out-

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lines of certain of the districts, enlarging some and reducing others. Probably some entirely new flowing-well districts may be found. The map has been compiled from the fullest data obtainable at this time.

LIFTING DEVICES.

Bucket and windlass.—A few open wells from which the water is drawn by buckets on a windlass are still in use. The owners of such wells are commonly convinced that water drawn in this way is superior in taste to that taken from a pump. There is always danger from pollution, however, in these wells by small animals or other objectionable matter entering the well mouth. A tight well cover should always be put in place when water is not being drawn.

Siphon.—The siphon principle may locally be utilized when running water is desired at some point below the level at which the water stands in a well. This system is used at the Kokomo city waterworks. A number of wells are drained by a siphon into a large well at the waterworks. The water is pumped directly from this large well.

Pumps.—Of the many pumps of various makes and kinds on the market, the greater number are so simple and so familiar as to need no description. For shallow wells the iron pitcher pump with the valve near the spout is much used. For open wells of moderate depths the wooden pump is popular. Most of the deeper dug, driven, or drilled wells for household and farm uses are equipped with iron force pumps with the valve below the water level. Some of these pumps are connected to windmills and may be pumped either by hand or by wind power. Factories, city waterworks, and large users of water in general employ water pumps operated by steam, gas, or gasoline. The chief types of power pumps are the reciprocating steam pumps, the air lifts, and the gasoline engines of various makes. Hot-air engines have also been used to some extent.

Hydraulic rams.—Throughout the area here discussed, but especially in the country districts, there are many flowing wells of good head and volume from which only a small fraction of the flow is used. If the pressure of these wells is sufficient to raise the water a few feet above the surface, or if there is a decline of the surface near the well, a hydraulic ram can be installed which will pump sufficient water for domestic and farm uses. The efficiency of hydraulic rams has been observed to vary from 30 to 71 per cent. That is, a ram at a well with a head of 10 feet and a flow of 10 gallons a minute will lift from 3 to 7 gallons a minute to a height of 10 feet, or 0.3 to 0.7 gallon to a height of 100 feet. Many houses in small towns or in the country are supplied with running water in this way, and water systems could be installed in many more at a small initial expense. The cost of maintenance of such a system is exceedingly small. In New

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alestine, Hancock County, there is a privately owned water system, ıpplied by artesian wells and pumped by a hydraulic ram, which ırnishes water to 20 or 30 families.

PUBLIC SUPPLIES.

In the area under discussion there are 54 towns and cities which ıave public water supplies drawing waters from surface streams, akes, wells, springs, or a combination of wells and streams, as follows:

Source of public supplies in towns and cities.

From lakes	3
From streams	3
From wells	44
From springs	1
From streams and wells	3

Of the public systems 48 out of 54 obtain all or part of their water from underground sources.

RELATIVE MERITS OF SOURCES.

SURFACE WATER.

In all regions as thickly settled as north-central Indiana the larger surface streams are sure to be contaminated to some extent, and the pollution may enter the streams in a number of ways. If towns or cities are located along the banks of a stream, the sewage is discharged into it. If there are no municipalities along the stream course, the drainage from dwellings and from manured fields or pastures is almost certain to supply objectionable organic matter. The salty or oily waters from the wells in oil or gas regions also are turned into the natural drainage channels. Even in the absence of sewage the streams all become turbid after every rain storm, so that for some time the water in its raw state is unfit for use.

The three cities which use river water altogether are Logansport, Anderson, and Mishawaka. The waters at Logansport and Mashawaka are unfiltered, and therefore subject to contamination. A filtration system has been installed at Anderson, and the filtered water is greatly superior to the raw water. At Indianapolis, Peru, and Goshen part of the water supply is from wells and the rest from streams. At Indianapolis White River water, used only after filtration, is very good. At Peru the water is ostensibly supplied from wells, but inasmuch as a considerable proportion of raw river water is constantly pumped into the mains the supply must be considered a serious menace to the health of the city. Part of the city water of Goshen is supplied from Rock Run, which flows for some distance through the town, having on its banks dwellings, barns, and outhouses that unquestionably pollute the water.

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Other things being equal, lakes are less likely to become contaminated than rivers, for their length of shore line is much shorter, as compared with the volume of water, than that of streams, and almost all pollution enters surface waters from the shores. It is, moreover, much easier to guard the shores of a lake from pollution than to control conditions along the banks of a stream which traverses a considerable stretch of country.

Three of the 54 municipalities are supplied from lakes. These are Warsaw, Rochester, and Syracuse. Center Lake, the source of supply at Warsaw, lies at the edge of the town, and the character of the water is questionable. The water from Rochester Lake at Rochester is itself of fair purity, but it becomes polluted in its passage through a mile-long mill race in the town. The conditions at Syracuse are much the same as at Rochester. Syracuse and Turkey lakes are bordered by extensive marshes, and the water is noticeably colored by organic matter, besides being exposed to contamination in its passage from the lake to the pumps through an open mill race. To summarize, in every instance in this area in which surface water is used for a public supply the water in a raw state is unsafe. In two instances it has, by careful filtration, been purified and converted into a very satisfactory supply.

The surface waters are superior to underground waters for many industrial purposes, because they contain a much smaller proportion of incrustants. This lower mineralization makes them especially desirable for locomotive-boiler supplies and for steaming purposes in general. On the other hand, the lower temperature of the ground waters especially recommends them for cooling purposes in brewing, distilling, and ice manufacture.

WELLS.

Of the 44 public supplies in which well water is used altogether or in part it is probably true that the worst of the well waters is as good as or better than the best of the surface waters mentioned above, in the raw state. Most of the well supplies are greatly superior to the surface supplies, at least with regard to their healthfulness. The wells at public waterworks are usually drilled deep in order to secure large quantities of water, and waters from deep beds are much less likely to be polluted than waters from near the surface. The wells for public supplies can be located at a distance from possible sources of contamination, and the ground around the wells can be guarded to prevent unhealthful conditions.

In a few towns in this area the wells for the public supply are shallow and are surrounded by barns, buildings, and dwellings, with the accompanying manure piles, slops, and privy vaults. It is a curious fact that people who are ordinarily careful about their habits

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of life should be careless about so vital a thing as the condition of their drinking water. Typhoid fever, one of the most dreaded forms of sickness in this area, is caused by the transfer of the infection from a typhoid patient into the alimentary system of another person. Contagion is spread largely through the pollution of drinking water by sewage which carries the typhoid-fever bacillus. Above all things a public water supply should be protected from this danger. Wells to be absolutely safe should be drilled or driven to a considerable depth, 50 or 60 feet at least, and should be lined with a tightly jointed iron pipe to keep out all the waters except those at the well bottom. Commonly, the deeper the well is the safer the water. If the wells are located at a distance from buildings or other sources of sewage, the danger is reduced to a minimum. In a few places it has been found to be impossible to obtain sufficient water from deep drilled or driven wells. Fairly safe waters may be obtained, as at Elkhart, from open dug wells if a considerable area of land around the wells is reserved and carefully guarded. Open wells should be several hundred feet from the nearest outhouse and carefully protected from surface wash to be safe from pollution.

SPRINGS.

Springs furnish the water for only one public supply in this region. At Delphi excellent springs emerge from a gravel terrace 3 miles northeast of the city, and the city waterworks collect this water and supply it to the people. There is every reason to believe that this supply is pure and good, but the common idea, that all springs are pure, is by no means true. Springs are subject to exactly the same dangers of pollution as wells. The waters are the same as those secured from wells, the only distinction being that springs have a natural instead of an artificial outlet. If the waters issue from shallow depths in towns or below manured pastures, near outhouses or barnyards, they should be avoided with the same care as should similarly situated dug wells.

CARE OF PUBLIC WATER SUPPLIES.

When sanitary conditions are assured for the wells at public waterworks, it is still essential that care should be taken to avoid all danger of pollution of the waters while they are stored and before their distribution through the mains. There is no danger of such pollution in tight iron standpipes which are covered over. Covered wooden tanks are also safe. Open tanks will receive slight deposits of dust and possibly some pollution from birds and insects, but this is likely to be of negligible quantity. Open reservoirs should be carefully guarded to prevent the entrance of surface waters or of sewage by

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underground circulation. Cement-lined reservoirs are safe except from surface wash and from dust and dead animals. The amount of dust should be unimportant and other pollution can be avoided by proper care. Cisterns, if tight, are safe, and if the surface of the stored water is kept above the level of the ground-water table any leakage from cracks will be outward from the cistern. Cisterns below the water table should be inspected as often as possible in order that means may be adopted to prevent the entrance from without of waters through cracks or flaws in the masonry.

In water mains in which the water is under pressure the pressure from within the pipes is much greater than that from without, and any defect in the pipes will cause a leak outward. No water from without can by any chance get into a high-pressure pipe. Where the water flows by gravity from one well to another, or where suction is used to draw water from wells or reservoirs a loose joint or hole in the mains might permit the entrance of sewage from without. Constant care is necessary to avoid such a contingency.

PUBLIC AND PRIVATE OWNERSHIP OF WATER SUPPLIES.

The obvious advantage of public water supplies over private wells is their greater convenience. With the constant pressure maintained in a municipal system, running water can be had at any time wherever it has been piped. Furthermore, there is the important advantage of abundant water and high pressure for protection from fire. But beside these two commonly recognized advantages, there is the all-important one, the health of the consumers, to be considered. In thickly settled communities, and especially in towns that have no sewerage system, a great quantity of liquid sewage is constantly soaking into the ground, some of which finds its way to the shallow wells used for drinking water. Such a condition is unpleasant to contemplate and extremely dangerous, but strangely enough it exists in most towns. Each well owner is sure that his water is the best in the world. He is accustomed to it, and it tastes just right to him. Yet examination of the water may show it to be heavily polluted. The best solution of the water problem is a carefully planned public supply. Wherever they are possible, deep driven or drilled wells are recommended. They should be located as far as possible from any source of pollution, and if practicable should be drilled to some water-bearing bed below an impervious bed of clay. These conditions should give a water supply far superior in every way to that obtained from shallow private wells.

Of the 54 public water supplies of this region, 19 are owned by private individuals or companies; 2 by the United States Government (at the National Military Home near Marion, and at Fort

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Benjamin Harrison); and the remaining 33 by the different municipalities.

There are certain advantages, both in municipal and in private ownership. The principal arguments in favor of private ownership of public water supplies are as follows:

1. The officials of a private water company do not hold office by political favor, but their connection with the business is permanent and their interest in and knowledge of the details is proportionately great.

2. As a result of better business methods, the cost of running a water plant is usually less in private than in public concerns.

3. The installation of improvements by a private company is simpler and does not require the tedious city-council legislation often necessary for such expenditures in a municipal system.

4. It is to the advantage of a private company to furnish as good and as cheap a supply as possible, in order to encourage the use of the system.

On the other hand, there are many advantages in a system owned by the town or city:

1. It is not necessary in a municipal system to charge enough for the water to pay a dividend on the capital invested.

2. In private companies there is always the tendency to insist that the water is pure, no matter what the actual conditions are. In municipal supplies there is a better opportunity for knowing the actual condition of the water.

3. It is not necessary, with a municipal supply, to postpone improvements until there is a sufficient increase in the receipts of the company to insure dividends on the cost of extension.

4. As the public officers hold their positions at the will of the people, there is a tendency for them to furnish as good a water supply as possible at a fair rate.

For these and other reasons municipal ownership of public waterworks has proved more satisfactory than private ownership in the area under discussion, as shown by the proportion of 33 to 19.

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Public water supplies in north-central Indiana.

[Abbreviations: A. l., air lift; a. p., air pressure; d. p., direct pressure; g. e., gasoline engine; gr., gravity; hy r., hydraulic ram; st. p., steam pumps; w. p. p., water-power pumps.]

Town.	County.	Owner of supply.	Source of supply.	Distributed from—	Capacity of reservoirs.	Elevation of reservoir above wells.	Carried to distributing point by—	Distributed by—	Length of mains.	Diameter of mains.	Number of taps.	Estimated proportion of population supplied.	Number of fire hydrants.	Average amount used daily.	Capacity of pumps per day.	Domestic pressure.	Fire pressure.	Analysis. No.	Analysis. Page.
					Gallons.	*Ft.*			*Mi.*	*In.*		*P. c.*		*Gallons.*	*Gallons.*	*Lbs.*	*Lbs.*		
Alexandria	Madison	City	7 wells	Standpipe	235,000	100	St. p.	Gr.	10	4–12	500	50	121	300,000	1,500,000	50	100–	5	175
Anderson	do	do	White River	Pumps	500,000	....	.....	D. p.	32½	4–20	2,200	33	288	1,500,000	6,000,000	65	100–	.....	.....
Argos	Marshall	do	1 well	do	25,000	....	.....	D. p.	3½	4–6	86	20	27	30,000	1,000,000	50	80	1	194
Bourbon	do	Union Water, Light and Power Co.	2 wells	Standpipe	65,000	100	St. p.	Gr.	....	4–10	70	15	27	50,000	.....	43	80	2	194
Bremen	do	City	5 wells	do	30,000	104	.....	Gr.	7	2–6	320	75	30	600,000	1,500,000	40	150–	4	194
Brightwood	Marion	City of Indianapolis.	3 wells	Pumps	40,000	....	.....	D. p.	6	¾–10	400	.....	39	93,000	1,400,000	40	100–	.....	.....
Camden	Carroll	E. C. Rice	1 well	Tank	.....	40	G. e.	Gr.	½	2	14	.....	0	.....	.....	.....	.....	2	86
Converse	Miami	City	1 well	do	3,500	72	St. p.	Gr.	2	4–8	180	60	.....	200,000	.....	32	32	3	202
Culver	Marshall	do	3 wells	A. p. tank	.....	....	G. e.	A. p.	¼	4–6	.....	.....	.....	.....	.....	.....	.....	5	194
Danville	Hendricks	do	6 wells	Standpipe	.....	200	St. p.	Gr.	5	4–8	600	95	40	450,000	1,500,000	120	120	4	149
Delphi	Carroll	do	Springs	do	37,000	116	St. p.	Gr.	5½	4–8	459	95	50	.....	1,500,000	55	80	6	86
Elkhart	Elkhart	Elkhart Water Co.	3 wells	Pumps	.....	....	.....	D. p.	33	6–24	3,320	25	281	3,000,000	19,000,000	55	100	2, 8	109
Elwood	Madison	Elwood Water Co.	14 wells	do	1,500,000	....	.....	D. p	14	4–14	1,100	40	149	650,000	5,000,000	40	100–	16	175
Fairmount	Grant	City	6 wells	do	.....	....	.....	D. p.	4	4–10	400	65	45	300,000	720,000	40	90–	2	127
Flora	Carroll	Flora Water Co.	1 well	A. p. tank	60,000	....	.....	A. p.	....	4–8	.....	.....	.....	.....	.....	45	75	12	86
Fort Benjamin Harrison.	Marion	United States	4 wells	2 standpipes.	.....	....	St. p.	Gr.	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Frankfort	Clinton	Frankfort Water Works Co.	12 wells	Pumps	400,000	....	.....	D. p.	23	4–12	2,000	75	229	1,000,000	5,500,000	50	90–	.....	.....
Frankton	Madison	City	1 well	do	.....	.....	.....	D. p.	4	.....	.....	40	31	25,000	300,000	60	110–	17	175
Galveston	Cass	W. H. Sprinkle	1 well	Tank	15,000	50	G. e.	Gr.	5	2–4	.....	.....	25	.....	150,000	35	.....	3	94
Gas City	Grant	City	3 wells	Pumps	150,000	....	.....	D. p.	....	Up to	500	60	46	.....	.....	30	100–	4	127
Goshen	Elkhart	do	2 wells and Rock Run.	Standpipe	266,000	146	St. p.	Gr.	25	4–20	1,800	80	292	1,500,000	8,000,000	60	100	13–15	109
Greenfield	Hancock	do	8 wells	Pumps	.....	....	.....	D. p.	8	4–12	900	75	84	300,000	1,000,000	45	100–	4	143
Greentown	Howard	Delon & Davis	1 well	Tank	10,000	65	G. e.	Gr.	1	½–3	95	25	.....	5,000 to 20,000	40,000	30	.....	.....	.....
Indianapolis	Marion	Indianapolis Water Co.	White River and wells.	Pumps	.....	....	.....	D. p.	284	4–36	18,863	75	2,291	17,883,800	90,000,000	65	125–	19, 20	186
Jonesboro	Grant	Trowbridge & Niver.	1 well	do	.....	....	.....	D. p.	....	4–10	150	33	52	225,000	1,500,000	45	130–	8	127

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Kewanna	Fulton	City	1 well	A.p.tanks			G.e.	A.p.	1½	Up to 6			13			40	75—		
Kokomo	Howard	American Water Works and Guarantee Co.	13 wells	Pumps				D.p.	30	4-12	2,500	75	295	2,000,000	7,000,000	40	100—	3-6	157
Lebanon	Boone	City	5 wells	Standpipe	189,000		St. p.	Gr.		4-12	1,400	60	124	600,000	2,000,000	50	52	2, 3	77
Logansport	Cass	do	Eel River	Pumps				D.p.	33	2-20	3,220	50	202	3,500,000	9,000,000	50	100		
Marion	Grant	do	14 wells	do	2,950,000		A.l.	D.p.				75			2,500,000	50	120	10, 12-15	127
Milford	Kosciusko	do	4 wells	Standpipe	83,000	110	St. p.	Gr.	2½	4-8	71	33	23	20,000	600,000	47	200—	7	165
Mishawaka	St. Joseph	do	St. Joseph River.	Pumps				D.p.	17	4-12	1,550	66	170	2,000,000	5,000,000	60	110		
Nappanee	Elkhart	do	3 wells	Tank	75,000	116	St. p.	Gr.	4	4-8	315	50	31	65,000		44	100—	19	109
National Military Home	Grant	United States	14 wells	Standpipe	240,000	125	St. p.	Gr.	3	4-8				500,000	2,000,000	60	150		
New Carlisle	St. Joseph	City	4 wells	Tank	33,000	85	St. p.	Gr.	2½	2-6		80	18	100,000	1,200,000	35	100—	5, 6	213
New Palestine	Hancock	Max Herrlick	2 wells	do	6,000	86	Hy.r.	Gr.	2	2	35	20	0		14,000	28			
Noblesville	Hamilton	Noblesville Water and Light Co.	17 wells	Pumps			St. p.	D.p.	13	2-16	750	35	102	480,000		40	80—	8, 9	137
N. Manchester	Wabash	City	12 wells	Standpipe	160,000	110	St. p.	Gr.	9		250	33	58	130,000	750,000	65	65	7	229
Peru	Miami	do	Wabash River and 14 wells.	Reservoir	1,200,000	93	St. p.	Gr.	24	6-16	1,765	65	221	1,300,000	3,000,000	39	100	14, 16	203
Pierceton	Kosciusko	do	1 well	Tank	15,000			D.p.	1½	4-6	200	50	32	20,000		40	60	8	165
Plymouth	Marshall	do	12 wells	Pumps				D.p.	7½	4-8	430	45	52		1,000,000	40	120—	16, 17, 18	194, 195
Rochester	Fulton	do	Mill race from Manitau Lake.	Standpipe	105,000		St. p.	Gr.	10			25		400,000				10	116
Royal Center	Cass	do	1 well	Tank	68,000	90	G.e.	A.p.	2	Up to 6			13	25,000		40	75	16	94
Russiaville	Howard	C. W. Hollingsworth.	2 wells	do	5,000	60	G.e.	Gr.		¾-2	20		6	5,000 to 20,000		30	60	10	157
Sheridan	Hamilton	G. H. Farmer	2 wells	do	10,000	65	St. p.	Gr.		¾-2	25	5		10,000	25,000	20			
South Bend	St. Joseph	City	70 wells	Standpipe	33,000	225	St. p.	Gr.	80	4-24	7,000	75	827	5,300,000	14,000,000	80	80	17, 18	214
Summitville	Madison	do	1 well	Pumps				D.p.	2½	4-8	130	50	25	150,000	750,000	40	120	29	176
Syracuse	Kosciusko	do	4 wells	Standpipe	32,000	95	W.p.p.	Gr.		4-10		20	27	15,000 to 30,000		45	120—	13	165
Tipton	Tipton	do	15 wells	Pumps				D.p.	13	4-12	900	66	81	350,000	500,000	30	120—	1, 2	220
Upland	Grant	Upland Water Works Co.	1 well	do				D.p.	¾	2-4	140	60		40,000	60,000	20			
Vanburen	do	E. S. Sutton	1 well	Standpipe	15,000	65	St. p.	Gr.	1½	2-5	130	25	12	75,000		30	110	23	128
Wabash	Wabash	Wabash Electric Light and Water Works.	9 wells	do	385,000	100	St. p.	Gr.	26	6-12	1,790	75	243	1,300,000	4,000,000	88 to 40	120	14, 15, 16	229
Walkerton	St. Joseph	City	4 wells	Tank	55,000	105	St. p.	Gr.	3	4-6		50	20	100,000		45	85	20, 21	214
Warsaw	Kosciusko	Winona Water and Light Co.	Center Lake.	Standpipe		125	St. p.	Gr.	7½	4-10	800	66	63	1,000,000	2,000,000	50	80	16	165

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DETAILED DESCRIPTIONS.

BOONE COUNTY.

SURFACE FEATURES AND DRAINAGE.

Boone County comprises 427 square miles and in 1900 had a population of 26,321, or 61 people to the square mile. Lebanon, the county seat, is in the center of the county, 25 miles northwest of Indianapolis.

This county extends along the divide between White and Wabash rivers and includes the highest land in Indiana west of White River. The surface has an elevation of 825 to 975 feet, or a range of approximately 150 feet (Pl. I). The greater part of the surface consists of slightly undulating uplands unbroken by any notable irregularities of surface. Across this plain and crossing the area from southeast to northwest is a narrow belt of low irregular hills. A part of another belt, of much the same character, crosses the southwest corner of the county. As usual in till-plain areas there is an almost complete absence of natural lakes or ponds. There are a few artificial ponds, used for stock, but the county as a whole is well drained.

The county contains no large streams. Eagle Creek flows along the eastern edge, and in the neighborhood of Zionsville its valley is about 60 feet below the level of the uplands. Sugar Creek, in the northwest corner, has also a well-developed valley. The other streams are still smaller and flow from 10 to 30 feet below the level of the upland.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Immediately below the surface in Boone County unconsolidated deposits which vary in thickness from 25 to more than 200 feet are everywhere present. They consist of alluvium, morainic drift, and pebbly till, and most of the wells draw their supplies from these materials. A general discussion of the character and water supplies of the surface deposits is given on pages 27–35.

The alluvial deposits are limited to the valleys of Sugar and Eagle creeks and to the flats of the still smaller streams. Their total area can not be more than a few square miles.

The moraines of this county (see Pl. I) are not of great height or thickness. In the moraine areas satisfactory wells can almost everywhere be obtained at moderate depths. The porous character of the deposits enables them to store large quantities of water and to yield it readily to wells. It is ordinarily not necessary to go through the drift into the underlying rock for sufficient water supplies.

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The larger portion of the county is a level till plain. The till ranges from 25 to 300 feet in thickness, notwithstanding the fact that its surface is flat and plainlike (Pl. II). This variation in thickness is due to the irregular surface of the underlying rock. The glacial ice moved over this surface and deposited enough detrital matter to fill the depressions and to level over the whole area.

The water moves very slowly through the fine-grained till, and to obtain it loosely curbed wells of large wall area have been much used. Of late years most of the open wells have been abandoned. It has been found that deep driven or drilled wells will almost certainly strike porous gravel beds in the till, and the gravel water so obtained is so much better and the supply so much more abundant than that from the clay that many people have preferred to bear the additional expense of sinking a deep well rather than to put in a cheaper shallow dug well. Drillers have been so successful in finding water in the till that few wells have gone through it into the rock.

CONSOLIDATED MATERIALS.

As stated above, the underlying rock formations are everywhere covered in this county by surface deposits, and no outcrops occur. Our knowledge of their distribution is derived altogether from comparisons with known outcrops in neighboring areas and from the records of well drillings. The probable distribution of the geologic formations is shown on Plate III.

The "Knobstone" group lying immediately below the till, in the west and southwest portions of the county, consists of limestones, sandstones, and shales. As a result of their superior hardness these rocks withstood the preglacial and glacial erosional agencies much better than the underlying New Albany shale. Wherever the "Knobstone" beds remain, they rise within 40 to 60 feet of the present surface. The older, less resistant shale has been deeply eroded beyond the edge of the "Knobstone," which, if the glacial materials were removed, would stand up as a sharp escarpment 100 to 200 feet above the shales to the east.

Over most of the areas underlain by the "Knobstone" the till has furnished sufficient water for domestic use. A few wells at Jamestown, Advance, Max, and in that part of the county south of Lebanon, have encountered a limestone 40 to 70 feet below the surface, which wherever penetrated has yielded abundant waters within a few feet of its top.

The New Albany shale underlies the surface deposits in all of central and eastern Boone County except the extreme northeastern corner (Pl. III). Although it is everywhere covered with till to a depth of 100 to 300 feet, this close-grained blue or black shale has been entered by the drill at many points. It contains much water, but it is

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so fine-textured that wells procure little or none. The formation is also too deep to be easily reached by the ordinary well-drilling rig.

Below the New Albany shale are two Devonian limestone formations known as the Sellersburg limestone and the Jeffersonville limestone, which are believed to outcrop below the drift in the extreme northeast corner of the county (Pl. III). The overlying drift is about 200 feet deep in this locality, and no records could be found of wells which have gone deeply into the rocks. No water is now drawn from them, and in Boone County it has yet to be determined whether these limestones contain available waters for wells.

ARTESIAN AREAS.

In Boone County there are six separate areas in which flowing wells have been found. In Plate IV these areas have been outlined and numbered.

In the northwest corner of Boone County, between Thorntown and Colfax, there is a narrow area about 4 miles in length, east and west, in which flowing wells may be obtained in the lowlands. (Pl. IV, No. 2.) These wells yield moderately and obtain their water in gravel at a depth of about 80 feet.

In the east edge of Thorntown, on the flat of Prairie Creek, there is a flowing well on the property of Mr. Samuel Jett. (Pl. IV, No. 3.) This well, which is 900 feet deep, was drilled in 1887 for gas, but gas was not found in paying quantities. In drilling an abundant supply of water was encountered in a gravel bed at a depth of about 90 feet. The drive pipe was drawn back to this bed and the well was plugged at 95 feet. It is reported that the well when first drilled would spout an 8-inch jet of water 7 feet above the well mouth. This indicates a flow of over 3,000 gallons per minute. The top of the well has now been plugged, leaving a small opening that leads to a hydraulic ram, which pumps abundant water for the house and barn. For a record of this well see page 76, No. 9, and for analysis of the water see page 77, No. 4. A number of the deeper wells in Thorntown, 30 feet above the creek flat, get water under artesian pressure, but they do not flow. It seems almost certain that other flowing wells might be obtained in the creek bottom both above and below Mr. Jett's well.

Between Lebanon and Hazelrig, along a low morainic plain and in the valley of Prairie Creek, is an area in which a number of wells that flow have been sunk. (Pl. IV, No. 4.) The flows were obtained in beds of gravel or coarse sand at a depth of about 50 feet. The yield of the wells is small and is growing more feeble with the general lowering of the water table.

Mr. J. F. Kersey, a well driller of Lebanon, reports that a flowing well was obtained north of Whitelick, on the farm of Mr. W. John-

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ston. (Pl. IV, No. 5.) This well was reported to be 60 feet deep and to have flowed 30 gallons per minute when first drilled. No further information was obtainable.

A flowing well is reported in the valley of Eagle Creek, on the farm of Mr. Perry Moore, 2½ miles northwest of Zionsville. (Pl. IV, No. 6.) This well is 81 feet deep and its water comes from a bed of sand and gravel in the glacial till. The water rises in the pipe 6 feet above the surface, and the flow is about 1 gallon per minute. It is probable that the area in which flowing wells may be procured is small.

SUPPLY FOR THE CITY OF LEBANON.

Lebanon, the county seat of Boone County, had in 1900 a population of 4,465, and is the only city in this county which has a public water supply. The supply for the waterworks, which are owned by the city and were built in 1894, was originally from three wells. One of these is a dug well 20 feet in diameter and 43 feet deep. It has a cement wall and receives all its water from a gravel bed at the bottom. The other original wells were 97 and 230 feet deep, and both received their supply from gravel beds. Since the plant was built four more wells, 8 inches in diameter and 97 feet deep, have been drilled, and one well was sunk to a depth of 816 feet. The materials penetrated by this well were as follows:

Partial log of deep well at Lebanon waterworks.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, clay, gravel	43	43
Stiff clay, gravel	54	97
Stiff clay, gravel	133	230
Shale, limestone	170	400

This well found no satisfactory supply. The pipe was later blown in two at 230 feet for the purpose of obtaining water at that depth, but the well was never productive and is now abandoned. The water from all the wells comes from gravel below blue clay, and there seems to be little likelihood of pollution from the surface. Up to January, 1908, this water was distributed from a standpipe with a capacity of 189,000 gallons, giving a pressure throughout the town of 45 to 50 pounds. A new underground cement reservoir, with a capacity of 500,000 gallons, was completed during 1907, and direct pressure from the pumps can be furnished in emergencies. Analyses of the water from the city wells are given on page 77, Nos. 2 and 3.

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In Lebanon many people still supply themselves with water from private wells, and although there are a few open wells in use the driven and drilled wells are in greater favor. In the west part of town water is obtained at depths of 40 to 60 feet; in the east part wells 100 to 300 feet deep are more common. Occasionally a drilling will fail to reach an open gravel bed in the till, and two or three have penetrated the underlying shale without obtaining satisfactory supplies of water. The records of a number of wells in and near Lebanon are given by Leverett.[a]

VILLAGE AND RURAL SUPPLIES.

Thorntown.—Thorntown, with a population of 1,511 in 1900, is situated on a till ridge which slopes downward to the valley of Prairie Creek on the east and to Sugar Creek on the north. The town has no public waterworks and all the supplies are obtained from wells, of which shallow, open wells 15 to 25 feet deep are most common. In a town of this size, as there is no sewer system, a large amount of objectionable matter from cesspools, barnyards, and other sources enters the ground to join the body of water from which the shallow wells are supplied, and such a supply is unsafe. On the other hand, there are a few drilled or driven wells which penetrate through a thick layer of till into a gravel bed, and the water there obtained is much safer than that from the shallow wells.

Thorntown should have a public water supply. The large flowing well in the creek bottom east of the town would easily furnish sufficient water for the entire village. The water is of good quality for domestic purposes, as shown by the chemical analysis on page 77, No. 4. Pneumatic pressure tanks or some other simple water system could be installed here at a relatively small cost, and would furnish fire protection, of which the town is greatly in need.

Section of deep boring at Thorntown.[b]

	Feet.
Drift	65
Subcarboniferous limestone and shale	238
Hamilton shale	87
Corniferous limestone	37
Niagara limestone	407
Hudson River and Utica	373
Trenton	80
	1,287

Whitestown.—Whitestown is situated on a till plain, and the wells, of various types, range in depth from 12 to 110 feet. The dug wells depend upon seepage water from the till, but the deeper driven and drilled wells enter lenses of gravel or sand and the supply from these

[a] Water-Supply Paper U. S. Geol. Survey No. 26, 1899, pp. 13-17.
[b] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 263.

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is more abundant. In one well 105 feet in depth the water rises within 9 feet of the surface and shows no variation in head either with the seasons or with heavy use. For the record and analysis of this water see page 76 (No. 14) and page 77 (No. 5).

Zionsville.—Zionsville lies in the lowlands near Eagle Creek, and the water table is nowhere far below the surface. Its water supply is drawn for the most part from shallow dug and driven wells, although there are a few drilled wells from 50 to 110 feet in depth. All the wells obtain water from gravel beds and none penetrates to rock. The deeper wells encounter water under artesian pressure. A well in the cellar of J. W. Brendel flows with a small stream 3 feet below the surface. (See p. 76, No. 15, and p. 77, No. 6.)

Jamestown.—The wells in Jamestown are drilled and dug, the dug wells getting water in the glacial clays or gravels and the drilled wells entering limestone at about 40 feet. The dug wells receive water through their walls at all levels and are subject to pollution, but the deeper drilled wells case off the surface waters, and are supplied only by the limestone, in which cool, palatable, and abundant water is commonly found. The town well, opposite the hotel, is drilled into rock.

Rural districts.—On the farms of the county wells supply water for domestic purposes and for watering stock. Most of them obtain their waters from the surface deposits, though a few enter the rock. Until within the last few years the open well was the rule, but with improved methods drilled and driven wells have gradually superseded the less sanitary dug wells.

Other communities.—The table below gives a list of other communities, with information regarding their water supply:

Other village supplies in Boone County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Advance	310	Wells, drilled, driven, and dug.	40	110	65	65	8	Gravel and limestone.
Bigspring	97	Wells, driven and dug; springs.	20	100	25	.....	10	Gravel.
Dover	46	Wells, dug and driven.	8	120	12	100	8	Sand, gravel, and limestone.
Gadsden	32	.....do.....	14	150	16	.....	12	Gravel.
Hazelrigg	64	.....do.....	11	96	15	.....	8	Do.
Max	134	Wells, driven, drilled, and dug.	10	125	20,75	70	4-15	Gravel and limestone.
New Brunswick	66	Wells, dug and driven.	20	150	25,60	.....	.....	Gravel.
Pike	.....	.....do.....	18	150	25	.....	16	Do.
Reese	127	.....do.....	40	150	45	.....	40	Do.
Rosston	100	.....do.....	15	175	20	.....	1-10	Do.
Royalton	149	.....do.....	10	116	25	.....	7-15	Do.
Whitelick	178	.....do.....	10	150	25	.....	13	Sand and gravel.

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TYPICAL WELLS AND ANALYSES.

The two tables that follow give complete information regarding a number of typical wells in Boone County and their waters. The numbers in the last column in each table refer to identical wells in the other table.

Records of typical wells in Boone County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Ft.		*In.*	*Ft.*	*Feet.*		*Ft.*	*Galls.*	*° F.*	
1	Town well....	¼ square S. of Advance railroad station.	90	Drilled..	2	90	− 8	Limestone..	60	.....	....	1
2	Otis Crane....	2½ miles E. of Hazelrigg.	47	Driven..	1¼	47	+ 2	Gravel.....	....	.....	....	...
3	Do.....	2 miles E. of Hazelrigg.	175	...do....	3	175	− 6	.....	....	.....	....	...
4	J. W. Wills...	Kirkland.....	51	...do....	2	51	.....	Gravel.....	....	.....	....	...
5	City of Lebanon.	At waterworks....	230	Drilled..	8	230	−20	.....do.....	230	.....	....	2
6	Do.....	.....do.....	816	...do....	8	.....	.....	.....	230	.....	....	...
7	Do.....	.....do.....	97	...do....	8	97	−20	Gravel.....	230	.....	....	3
8	George W. La Follette.	1 mile SE. of Shannondale.	60	...do....	4	60	+ 7	Blue limestone.	30	.....	51	...
9	Samuel Jett...	E. edge of Thorntown.	1,700	...do....	8	90	+12	Gravel.....	....	.....	....	4
10	Albert Wetherald.	3½ miles NW. of Thorntown.	187	Driven..	2	120	−10	Clay.....	....	.....	....	...
11	John Leatherman.	3 miles NE. of Thorntown.	140	Drilled..	4	....	+ 4	Sand.....	....	.....	50	...
12	J. E. Leatherman.	3½ miles NE. of Thorntown.	140	...do....	4	140	+ 7	Gravel.....	....	.....	....	...
13	Willis Johnston.	1 mile N. of Whitelick.	60	...do....	2	60	+ 5	.....	....	30	....	...
14	Isaac Isenhour	Whitestown.....	105	...do....	4	105	− 9	Gravel.....	....	.....	....	5
15	Jas. W. Brendel.	Zionsville.....	108	...do....	3	108	− 3	.....do.....	....	.....	....	6
16	Town well....	At Farmers' Bank, Zionsville.	.....	Open....	....	.....	.....	Till.....	....	.....	....	8
17	A. Perry Moore.	2½ miles NW. of Zionsville.	81	Drilled..	2½	78	+ 6	Gravel and sand.	....	1	54	...

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Mineral analyses of waters in Boone County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of well.
1	Public well	Advance	Drilled well, 90 ft. by 2 in.	H. E. Barnard	1907	Limestone	...	0.01	...	61	25	...	...	0.0	366	0.0	16	0.20	0.001	2	412	1
2	City supply	Lebanon	Drilled well, 230 ft.	Chase Palmer	1907	Gravel	24	2.3	...	78	37	99		24	564	1.6	4.2	.05	.....	...	622	5
3	.....do	.....do	Drilled well, 97 ft.	.....do	1907	.....do	24	.4	..	53	30	31		14	301	3.6	2.5	4.0	.....	...	352	7
4	Samuel Jett	Thorntown	Drilled well, 1,700 ft.[a]	.....do	1907	.....do	22	1.0	...	67	28	50		7.2	378	9.5	12	.0	.....	...	390	9
5	Isaac Isenhour	Whitestown	Drilled well, 105 ft. by 4 in.	H. E. Barnard	1907	.....do	...	1.2	...	64	27	...	...	.0	451	.0	12	.05	.001	4	512	14
6	J. W. Brendel	Zionsville	Drilled well, 108 ft. by 3 in.	.....do	1907	.....do	...	.01	...	114	35	...	...	.0	345	120	112	4.0	.001	4	754	15
7	Zionsville Water and Electric Co.	.....do	Wells	.....	.....	.....	10	4.4		96	22	14		163	....	57	22	.....	.....	...	432	....
8	Public well	.....do	Open well	H. E. Barnard	1907	Till	...	.4	...	49	28	...	...	.0	388	.0	32	.05	2.0	9	454	16

[a] Water from only 90 feet below the surface.

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CARROLL COUNTY.

SURFACE FEATURES AND DRAINAGE.

Carroll County, which lies on the western edge of the area treated in this report and halfway between its northern and southern borders, has an area of 370 square miles and in 1900 had a population of 19,953. That part which lies east and southeast of Wabash River is a dissected till plain with level upland areas between the valleys of the larger streams. A few small areas of terminal moraine give locally a somewhat more rolling topography (Pl. I), and an area of irregular moraine lies between Wabash and Tippecanoe rivers.

Carroll County is exceptionally well provided with surface streams, the most important being Wabash River, which crosses the northwest corner of the county. The valley of this river is broad and well developed, and varies in width from one-half mile to 2 miles. The river lies 100 to 130 feet below the surrounding plain, and its valley bottom is occupied by alluvial deposits of low slopes. Above the bottom lands the bluffs rise sharply for about 100 feet and then merge with the till plains of the upland. The lowest point in the county is where Wabash River crosses the county line below Delphi, about 575 feet above sea level; the highest point in the county is about 800 feet above sea level, giving a range of elevation of approximately 225 feet.

Next in importance to the Wabash is Tippecanoe River, which flows along the west edge of the county. Its valley is neither so broad nor so deep as that of the Wabash and is less than 100 feet below the uplands. It varies from one-fourth to 1 mile in width, and the bluffs at the valley sides are steep. The Tippecanoe joins the Wabash 3 miles south of the county line.

Wild Cat and Deer creeks are both important streams, and flow from east to west across the county to join the Wabash. Both these creeks have developed flood plains in proportion to their size, and they, with numerous smaller streams, have aided in dissecting the till plateau.

As a result of the complete drainage of this county, there are no large natural lakes or ponds. A few artificial ponds have been formed by damming a stream valley or a gully, but all are small.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

In the valleys of Wabash and Tippecanoe rivers and of Wild Cat and Deer creeks, as well as in the valleys of many smaller streams, there are alluvial plains of varying width. The alluvium occurs either as flood-plain flats, usually known as the "first bottom," or as

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terraces above the flood plain. The terraces that lie at different heights up to 75 feet above the stream are remnants of older flood plains, which have been partly removed since their formation. In the Wabash Valley the stream deposits vary in thickness up to 30 feet, or may be missing, for in flood time the river scours its channel down to bed rock.

The alluvial beds have a large pore space, and a capacity for holding a great deal of water, almost all of which is readily available if reached by wells. In the valley bottoms sufficient water is usually present to saturate the alluvium well up toward the surface, so that conditions are ideal for obtaining plentiful water at shallow depths. For farm use driven wells have been found to be cheapest and most satisfactory for procuring waters from alluvium, and they are in general use wherever these deposits occur.

The moraines of Carroll County are nowhere prominent topographic features. They occur as disconnected patches (see Pl. I), with bowlder-covered surfaces of slight relief, and the low hills nowhere stand more than a few feet above the surrounding plains. Those patches which occur near Wabash River are outlying remnants of the great interlobate moraine which extends from Carroll County northeast into Michigan. There is generally enough gravel or sand in the moraines to afford domestic wells a fair yield of water from drilled or driven wells. In the absence of coarse beds open wells in the bowlder clay will obtain moderate amounts of seep water.

The till, which covers most of the surface of the county, is generally thickest on the stream divides and thinnest along the valleys. In a number of valleys the streams have cut entirely through the till, exposing the bed rock below; in other places, as at Cutler, wells 150 feet deep have failed to reach the bottom of the till. At Delphi Wabash River has removed the glacial deposits and exposed the rocks. In those areas where porous gravel or sand beds occur in the till water can be best obtained by drilled or driven wells, although such beds are in many places too deep to be easily reached by open wells. The only recourse in those areas where gravels and sands are absent is to sink open dug wells, into which the water seeps gradually from the till.

CONSOLIDATED MATERIALS.

The New Albany shale, which underlies the surface deposits in the southwest half of the county (see Pl. III), outcrops near Delphi and in the valley of Rock Creek, but is covered, except in the deep valleys, by surface deposits up to 150 feet thick. These black shales seldom serve as the source of well supplies, for although the pore space is large and the proportion of water contained is considerable, this water is not yielded to wells unless well-defined open passages are

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encountered. In Rockfield one or two wells have obtained good supplies from this shale.

The Devonian limestones are the uppermost beds of rocks in much of eastern and northern Carroll County (Pl. III). Most of this area is covered by the till plateau, and the only reported outcrops of these limestones are along Wabash River above Delphi and in Rock Creek east of Tilman. Only a few wells have penetrated the limestones, though such wells have always been successful. A well north of the village of Darwin obtained a fine supply when the drill in limestone dropped 8 inches into an opening of some sort. As the overlying drift nearly everywhere furnishes enough water it is unnecessary to sink to the rock.

A limestone which is usually classed with the Niagara but which has also been referred to as Devonian, outcrops at the surface in the neighborhood of Delphi, and forms the rock surface below the drift in a portion of the east and north parts of the county (Pl. III). The fracture joints, solution passages, and bedding planes of the limestone are filled with water to a level within 12 or 15 feet of the surface. Below this level drilled wells commonly find good supplies of water in the openings of the rock. Wells drilled into the rock should be put down to a considerable depth and cased for some distance below the ground-water level, as the deeper waters are less likely to be contaminated than those nearer the surface. The broad outcrops of limestones are so broken that any liquid matter is readily absorbed at the surface and shallow rock wells might easily be polluted in this way.

ARTESIAN AREAS.

At Delphi waters under artesian pressure have been found in all borings that have gone deeply into the "Niagara" limestone. (Pl. IV, No. 7.) Two such wells are now flowing, the best known of which is the "Delphi artesian well,"[a] drilled originally for gas or oil to a depth of 912 feet.

Section of deep well at Delphi.[b]

	Feet.
Niagara limestone	587
Hudson River limestone and shale	220
Utica shale	93
Trenton limestone	12
	912

The principal flow of water is said to come from a depth of 165 feet, but the temperature of the water (57° F.) would indicate that at least part of it comes from greater depths. The water is much

[a] Described by J. N. Hurty, Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., pp. 29-30.
[b] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 241.

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used for drinking. A second well, producing a similar water but yielding a smaller flow, is situated at the Monon Railroad bridge across Deer Creek.

Two flowing wells are reported from the Wabash Valley northwest of the village of Burrows. (Pl. IV, No. 8.) As limestone outcrops along the river in this neighborhood, it is presumed that these wells enter rock.

Along the valley of Sugar Creek, near Radnor, there is an area in which good flowing wells have been obtained. (Pl. IV, No. 9.) There are five flowing wells in this valley, which range in depth from 29 to 39 feet. All but one of these were put in during 1907. The artesian waters occur in a gravel bed in the till and are obtained by driven wells, which can be sunk here for 75 cents per foot. A complete flowing well may thus be obtained at a cost of less than $30.

At Burlington, near Wild Cat Creek, there are several flowing wells. (Pl. IV, No. 10.) The only one of these about which information could be obtained was drilled to a depth of 97 feet, the lower 7 feet being in limestone, from which the flow was obtained. The well is on the slope of the river bluff, about 35 feet above the creek, and the water is used at a creamery. There is good reason to believe that other flowing wells may be obtained in this neighborhood if situated upon ground as low as or lower than the creamery and drilled into the limestone.

CITY AND VILLAGE SUPPLIES.

Delphi.—Delphi, the county seat of Carroll County, is situated in the broad valley of Wabash River and about 30 feet above that stream. It has one of the best city water supplies in Indiana, obtained from springs about 3 miles northeast of the city. The springs are three in number, and issue from the base of a gravel terrace which rises about 40 feet above them. In the present waterworks, which were built in 1891, the water is collected from the springs, which are covered by spring houses, and carried by gravity through wooden pipes to a buried reservoir of 387,000 gallons capacity. From the reservoir it is pumped by steam to a 37,000 gallon standpipe, 116 feet high, from which the water is distributed by direct pressure to about 5½ miles of city mains, ranging from 8 to 4 inches in diameter. There are 459 service taps, which supply more than 90 per cent of the people of Delphi. Practically everybody in the city proper depends upon the city supply, but in North Delphi and the later additions the city water is not so generally used.

The healthfulness of the water supply is attested by the general health of the city. There is no record of a single case of typhoid fever among the people who use only the city water. Up to the pres-

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ent time the supply has been adequate, but additional water will be needed if the growth of the city continues.

A large additional supply could be obtained from springs known as "Falling Springs," 2 miles southwest of the court-house, between the Wabash Railroad and the river, near the county line. These springs apparently emerge from above the rock and below the till and are cold and clear. The land above is under cultivation, and there are no houses near by, so there is little danger of pollution of this water. The flow of the largest spring is estimated at 100 gallons a minute, enough to supply at least 50 per cent of the present population of the city. There are many other large springs which issue from the bluffs of the Wabash above and below Delphi.

In the outskirts of the city a good many families rely on cisterns and shallow wells for their water. Such wells are either in the surface alluvial gravels or in the upper part of the limestone, and waters from either source are likely to become contaminated, especially near settlements.

It is reported that some wells in the limestone have been spoiled by the artesian sulphur waters from unplugged gas wells. The state law which requires that all abandoned wells must be plugged at the base of the limestone should be more strictly enforced, as the leakage from such wells is continuous when the waters are under artesian pressure and may affect the upper waters for considerable distances from the wells.

Flora.—Flora, with a population, in 1900, of 1,209, is a thriving town situated on the till plateau, 8 miles southeast of Delphi. A public supply was installed in the summer of 1907 by the Flora Water Company, a part of the stock in this company being owned by the city. An 8-inch well has been drilled to a depth of 195 feet, of which the last 60 feet are in limestone. The principal water supply was obtained at 185 feet, and none was found below this. The well was tested and was found to yield 100 gallons per minute during a half day's continuous pumping.

A pneumatic pressure system with two 60,000-gallon tanks is used. The water is pumped into the tanks, which are partly filled with air, and the air pressure forces the water through the mains, of which there are about 3 miles, 8, 6, and 4 inches in diameter.

Before the installation of the public system the town was supplied by private wells, most of which were shallow driven wells, obtaining water in the sand and gravel in the till at depths of 16 to 40 feet, though a few drilled wells which enter rock at about 140 feet were used. The shallow wells are dangerous and to their use may perhaps be ascribed the prevalence of typhoid fever in the town at certain times.

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Camden.—Camden is situated on a gently undulating till plain near Deer Creek and about 5 miles east of Delphi. It has no public supply in general use, although there is a small private system, the water from which is used for sprinkling. The water for this system is obtained from a 185-foot drilled well, sunk 65 feet into limestone, and the water obtained from this limestone is pumped by a gasoline engine to a tank 40 feet high, from which it is distributed by gravity. The system has 1,500 feet of 2-inch mains and supplies 14 taps. Only 20 barrels of water per day are consumed. An analysis of this water is given on page 86 (No. 2).

In Camden most of the water for domestic use is obtained from open wells 15 to 30 feet deep, which secure water from gravelly beds or from seepage from the clay. The open wells are always a source of danger, as they readily receive any drainage from kitchen slops, outhouses, or any other liquids which may be absorbed at the surface. Wherever it is possible, water from the deep wells should be used and the open wells abandoned and filled up.

Burlington.—The village of Burlington is situated on the edge of a rolling till plain near the valley of Wild Cat Creek, and about 60 feet above it. Beneath the town the till is 130 to 140 feet in thickness, so that most of the wells are driven into gravel in the till, although a few deep drilled wells go into the limestone at the base of the till and get water under artesian pressure. On the slope of the bluff and below the plain some wells in limestone will flow at the surface.

A number of large springs issue from a gravel bed near the base of the creek bluffs, the largest of which, on property belonging to the heirs of Amos Miller, flows about 15 gallons per minute. The spring emerges from just below the cemetery, and there is a possibility of pollution from this source.

Pittsburg.—Pittsburg lies on a narrow strip of terrace and on the side of the bluff of Wabash River, opposite Delphi, and its water supply is obtained from springs and dug wells. The springs flow out from the base of the bluff, apparently from gravel beds. One of the best of the springs is owned by the county, and its water, which has been piped to a watering trough at the principal crossroads, is used by many families for drinking purposes. The wells in the town are almost all of the open type. Near the river they reach to limestone at depths of 12 to 15 feet, but on the higher ground the limestone is deeper, and the water is found in gravel beds in the till. In a 60-foot section of the till, offered by a cut along the Monon Railroad, at the edge of the town, the upper 30 feet consist of beds of oxidized gravel which have been cemented into a conglomerate. Below these the section consists of blue, unoxidized till.

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Other communities.—A tabulated list of other communities in the county, with the conditions of water supply in each, is given below:

Other village supplies in Carroll County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Bringhurst...	448	Wells, drilled and dug...	14	120	65	125	12	Gravel and limestone.
Burrows.....	187	Wells, driven and drilled.	35	90	35	.....	20	Gravel and sand.
Cutler.....	150	Wells, dug and drilled...	12	150	80	.....	6–12	Gravel.
Darwin.....	.....	Wells, dug and driven ..	10	96	15	.....	10	Do.
Deer Creek...	120	Wells, dug and drilled...	10	175	12	50–60	.....	Gravel and limestone.
Hopedale....	25	Dug wells and springs...	13	150	40	.....	3–20	Gravel.
Lockport.....	117	Wells, driven and dug...	20	115	30	22	.....	Gravel and limestone.
Ockley.....	102	.....do.....	18	106	70	.....	16	Gravel.
Owasco.....	30	Wells, dug.....	19	40	30	.....	4–35	Do.
Patton.....	75	Wells, dug and driven...	12	115	20	.....	8	Do.
Pyrmont.....	100	Wells, dug.....	18	30	20	.....	15	Do.
Radnor.....	150	Wells, dug and drilled...	15	55	15	.....	5	Do.
Sleeth.....	46	Wells, dug and driven...	11	14	12	.....	10	Do.
Walker.....	25	Wells, driven.....	30	130	45	135	10	Gravel and limestone.
Wheeling....	177	Wells, dug and drilled...	20	118	30	.....	.....	Do.
Yoeman.....	50	Wells, driven and dug...	16	60	20	.....	.....	Gravel.

Rural districts.—In the county there are great numbers of wells for household use and for watering stock. Some of these are in the surface deposits, and some go into the underlying rock. In the matter of deep driven and drilled wells, the inhabitants of Carroll County have been rather backward, and there are still an unusually large number of open wells in use. The popularity of the driven and drilled wells is increasing, however, and almost all new wells are of one of these two types.

Carroll County is especially fortunate in the possession of a large number of springs. Most of these rise from the base of the bluffs along stream valleys, and the waters, always cold and clear, are commonly free from contamination and where available afford an unexcelled supply.

TYPICAL WELLS AND ANALYSES.

The two following tables give detailed information regarding typical wells in Carroll County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

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Records of typical wells in Carroll County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Feet.*	*Gallons.*	° *F.*	
1	Henry Carter	Bringhurst	103	Drilled	2	100	−16	Gravel				
2	D. F. Beck	Burlington	97	do	2	90	+	Limestone	90			
3	Fort Wayne and Wabash Valley Traction Co.	Burrows	37	Driven	2	37	−20	Gravel				1
4	E. C. Rice	Camden	185	Drilled		150	−40	Limestone	120			2
5	Daniel A. Eller	do	125	do	4	125		do	113			
6	Philip Ray	do	25	Dug				Drift				3
7	J. E. Snell	Carroll	20	do			−10	Gravel				
8	Dr. G. L. McNeal	Deer Creek	176	Drilled		176	−12	Limestone	60			5
9	Odd Fellows	do	13	Dug				Drift				4
10	John Crecraft	Flora	200	Drilled	4	200	−32	Limestone	149			11
11	Public well	Center and Columbia sts., Flora	28	Driven	2	28	− 6	Gravel				12
12	Jerome Etter	North Delphi	35	Drilled	4		−10	Limestone	2			9
13	Price Shortridge	Patton	103	do	2	100		Gravel				
14	R. A. Newell	¼ mile W. of Pyrmont	100	do	4	100		do				
15	John Closson	Radnor	29	Driven	1¼	29	+ 8	do		8	52	14
16	Charles Raber	Rockfield	92	Drilled	2½	40	− 7	Shale	40		51	
17	W. A. Trobaugh	South Delphi	14	Driven				Gravel				10
18	Harvey Ross	SW. ¼, sec. 24, T. 25, R. 2	145	Drilled	3	140	−50	Limestone and shale	52		52	
19	John Brookie	Walker	98	do	4	98	−25	Gravel				

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Mineral analyses of waters in Carroll County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Fort Wayne and Wabash Valley Traction Co.	Burrows.....	Well, 37 ft....	H. E. Barnard	Nov., 1907	Gravel.....	....	0.8	....	117	44	....	....	0.0	295	130	14	0.10	.000	4	562	3
2	E. C. Rice.....	Camden.....	Well, 185 ft.[a]	.....do.....	...do.....	Limestone.....	....	1.0	....	84	30	....	....	.0	306	25	2.0	.70	.000	13	374	4
3	Philip Roy.....	.....do.....	Open well, 25 ft.	.....do.....	...do.....	Drift.....	....	.40	....	127	37	....	....	.0	300	64	36	7.00	.000	9	632	6
4	Odd Fellows.....	Deer Creek....	Open well, 13 ft.	.....do.....	...do.....	.....do.....	....	.00	....	136	44	....	....	.0	347	60	71	2.00	.000	23	706	9
5	Dr. G. L. McNeal.	.....do.....	Well, 176 ft....	.....do.....	...do.....	Limestone.....	....	1.00	....	84	34	....	....	.0	303	1.2	22	.40	.001	19	414	8
6	City supply.....	Delphi.....	Springs.....	R. B. Dole....	Sept., 1907	Gravel.....	21	.07	....	81	24	4.4		.0	350	32	1.4	16	.....	.....	332	.....
7	C. B. Landis.....	.....do.....	Spring.....	.....do.....	.....do.....	.....do.....	25	.06	....	46	22	2.5		8.4	189	11	1.0	30	.....	.....	243	.....
8	.....	1½ miles SW. of Delphi.	"Falling springs."	H. E. Barnard	Nov., 1907	.....do.....	....	.1	....	101	31	....	....	.0	299	26	3	2.00	.001	9	420	.....
9	Jerome Etter.....	North Delphi.	Well, 35 ft. by 4 in.	.....do.....	...do.....	Limestone.....	....	1.60	....	72	37	....	....	.0	224	34	8.0	3.00	.02	4	266	12
10	W. A. Trobaugh..	South Delphi.	Well, 14 ft.....	.....do.....	...do.....	Gravel.....	....	.05	....	106	33	....	....	.0	282	58	32	4.00	.002	9	534	17
11	John A. Crecraft..	Flora.....	Well, 200 ft. by 4 in.	.....do.....	...do.....	Limestone.....	....	.30	....	66	33	....	....	14.0	232	29	82	.10	.001	23	646	10
12	Public well.....	.....do.....	Well, 28 ft. by 2 in.	.....do.....	...do.....	Gravel.....	....	.20	....	111	30	....	....	.0	316	35	8.0	.05	.000	13	546	11
13	County.....	Pittsburg.....	Spring.....	.....do.....	...do.....	.....	....	.80	....	122	36	....	....	31.0	207	65	18	12	.001	9	496	.....
14	John Closson.....	Radnor.....	Well 29 ft. by 1½ in.	.....do.....	...do.....	Gravel.....	....	.6	....	116	33	....	....	.0	302	18	2.0	.10	.001	4	384	15
15	T. G. Timmons...	Rockfield.....	Open well, 10 ft.	.....do.....	...do.....	.....do.....	....	.01	....	194	71	....	....	.0	274	396	41	.70	.001	4	1,048	.....
16	J. E. Snell.....	Carroll.....	Open well, 20 ft.	.....do.....	...do.....	.....do.....	....	.00	....	89	38	....	....	.0	252	80	74	3.00	.000	23	770	7
17	I. N. Wagner.....	.....do.....	Drilled well, 118 ft.	.....do.....	...do.....	Limestone.....	....	.20	....	36	33	....	....	.0	199	9.5	2	.10	.00	9	348	20

[a] Water from 150 feet.

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CASS COUNTY.

SURFACE FEATURES AND DRAINAGE.

Cass County, in the west-central part of the region under consideration, has an area of 420 square miles. Its population in 1900 was 34,545, an average of 82 inhabitants to the square mile. The county seat, Logansport, 68 miles from Indianapolis and 100 miles from Chicago, lies a little northeast of a line connecting these two greater cities.

The county exhibits more diversity of surface than many equal areas within the State, chiefly because it contains parts of two important stream valleys. The most striking topographic feature is the valley of the Wabash, which crosses the county from east to west as a very definite trough that ranges in width from a few hundred feet to a mile and is incised from 100 to 150 feet below the level of the uplands north and south of it. The valley of Eel River, roughly parallel to that of the Wabash, joins the latter at Logansport, and is a similar but slightly less prominent topographic feature.

The uplands north of the Wabash Valley are diversified by low morainal hills, and another belt of similar irregular topography occupies the strip between Deer Creek and the south line of the county. Except where streams are cut below them or moraines rise above them the uplands are flat, featureless plains.

The Wabash and the Eel are the chief streams of the county, as their valleys are the principal depressions. Where either river has cut below the glacial mantle into the underlying rock its valley is narrow, its banks are cliff-like, and its channel is impeded by rapids, but in the drift areas the valleys broaden, and the water courses are bordered by narrow belts of alluvial bottoms. The other streams of the county are small and their valleys are cut but a few feet below the level of the uplands across which they flow.

A few small lakes in the northern part of the county, like other lakes in northern Indiana, occupy depressions in the morainal drift. Lake Cicott, the largest, 9 miles west of Logansport, is 1 mile long and one-fourth mile wide. The county as a whole is well drained and contains no large marshes.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The alluvial sands and gravels, since they are stream-laid deposits, are confined practically to the strips of bottom and bench land that border the rivers. Not every terrace, however, overlies deposits of this character, for in a few localities, where the streams flow over rock, the benches also are cut in rock which may be veneered by a

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film of alluvial gravels a few feet or a few inches thick. Deposits of the strictly alluvial type in this county are confined almost entirely to the valleys of Wabash and Eel rivers, but in the western part, north, west, and south of Lake Cicott, there are similar surface deposits of sand.

Water is generally abundant, of good quality, and easily obtained in the bottom lands. The alluvium remains saturated at least up to the level of the streams, so that wells sunk in it are less affected by drought than those in the glacial deposits of the uplands, and the thorough washing and sorting that the material has undergone during the process of deposition has removed from it much of the mineral matter that it originally contained, so that the water obtained from it is softer than that from the till, and, where protected from contamination, is pure.

Driven wells are easily and cheaply installed in the bottom lands, and few fail to yield a supply that is excellent and ample for all purposes.

Morainal drift occupies the greater part of the upland surface of Cass County, the underlying till, at places scarcely distinguishable from it by the drillers, appearing at the surface only in two areas, one south of the Wabash, between it and Deer Creek, the other in the north half of the county (Pl. I).

The thickness of both the moraine and the till varies in different parts of the uplands. Southwest of Adamsboro, between Wabash and Eel rivers, wells 100 feet deep do not reach rock, and the topography of this divide indicates that the greater part of this thickness is morainal material. North of Eel River the moraine may be even thicker, while along the south edge of the county it is so thin that all except the shallowest wells pass through it into the till below.

In the areas of rougher topography the drift is almost everywhere of open texture, permitting free circulation of water. Wells sunk in these areas yield abundantly, but the water table is at many places 50 to 70 feet below the ground surface. Because of the free circulation and the abundance of the supply, however, continued pumping fails to lower the water level. In those morainal areas where the relief is less marked the water table is nearer the surface.

The till, wherever it may be found either beneath the moraines or at the surface, where it forms a level or slightly undulating plain, is of the usual type—that is, it is a compact clayey mass which yields water but sparingly except from interbedded sand or gravel layers. These layers, however, are in most localities sufficiently abundant to make it highly probable that any deep drilled well will pass through one or more such beds, from which abundant water may as a rule be procured.

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Generally speaking, the waters derived from the till are the hardest that are obtained from the unconsolidated materials in this county, those derived from the moraines being next in hardness.

CONSOLIDATED MATERIALS.

The Devonian limestones, the youngest of the hard rock deposits of Cass County, immediately underlie the glacial material in the south-central part of the county and appear at the surface in the valleys of Wabash and Eel rivers. Beneath the Devonian in this part of the county and just below the drift throughout the remainder of the county lie the Silurian ("Niagara") limestones. These limestones also outcrop in the valleys of Wabash and Eel rivers east of the zone along which the Devonian beds appear. Deep borings at Logansport indicate a thickness of 540 feet for the Silurian there and prove that several so-called "breaks" or beds of shale are interstratified with the more massive limestone. These shale layers serve as confining beds and, where other conditions are favorable, make possible the accumulation of sufficient head in the water beneath them to cause it to flow at the surface.

The depth to rock varies widely within the county. The fact that it appears at the surface in the valleys of the Wabash and the Eel has already been mentioned. In the southern half of the county scattered wells reach the Devonian rocks, but in the area north of the Wabash the Silurian is so deeply buried that few wells extend to it.

Some wells obtain good supplies of water from the unconsolidated beds just above the limestones, but better yields are almost everywhere to be had from the rock itself a few feet below its upper surface. Both of the limestones are intersected by open joint and bedding planes that form crevices which afford free passage for water. These crevices are especially numerous near the surface of the rock, and few wells that penetrate it for a short distance fail to obtain an abundant supply. Plate V, *B*, shows solution passages in the limestone. Such openings, if encountered by wells, commonly supply large quantities of water.

ARTESIAN AREAS.

At the Northern Indiana Insane Asylum at Longcliff, 2 miles southwest of Logansport, there are two deep wells in the limestone, one of which flows 2 and the other 3 gallons a minute. (Pl. IV, No. 11.) One of these wells is 230, the other 618 feet deep, but as neither of them is cased below the rock surface the depth from which the water rises is not known.

Near the southern edge of the county, along the lowlands of Deer Creek and its tributaries, is another area of flowing wells. (Pl. IV, No. 12.) The surface deposits here are 50 or 60 feet thick, and the

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wells passing through this mantle strike the artesian water in the upper part of the underlying limestone. The conditions that cause this flow, shown diagrammatically in figure 12, seem simple and clear. In the vicinity of Kokomo the limestones are near the surface, and so are favorably situated for the absorption of rainfall. Between Kokomo and the Deer Creek lowlands the limestones are covered by a sheet of impervious till, which confines the water sufficiently to give it the necessary head.

At Galveston, in the southeast corner of the county (Pl. IV, No. 13), there is an old well, drilled originally for gas, that yields about 20 gallons of water a minute. This water is under sufficient pressure to rise over 5 feet above the surface. No record of the well could be obtained, but there can be little doubt that the water comes from the "Niagara" limestone, which is here 40 to 60 feet below the surface. The fact that the water is sulphurous (analysis No. 4, p. 94) adds to this probability. It is likely that the head which causes this water to flow originates farther east and south.

In the Wabash Valley in the vicinity of Logansport all of the deep wells in the limestone encounter water under artesian pressure. In a number of these the pressure is sufficient to produce a flow. (Pl. IV, No. 14.) The strongest yield is reported from a boring for gas, said to be the deepest in Cass County. This well, the property of John W. Kennedy, is in the west end of the city. When it was first drilled the water is said to have spouted 2 feet above the top of the 6-inch casing, indicating a yield of nearly 1,000 gallons a minute at that time. Since then the well has been plugged to stop the waste.

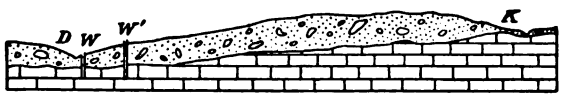

FIGURE 12.—Diagram showing source of artesian head in the valley of Deer Creek. At Kokomo (*K*) the limestone is near the surface and can absorb the rainfall. Between Kokomo and Deer Creek (*D*) the rock is covered by a sheet of impervious till. In the valley of Deer Creek the water, which is under artesian pressure, will flow at the surface at *W*. At *W'* the water from the same depth will rise toward the surface but will not flow.

In addition to the flowing wells there are in Logansport many rock wells in which the water rises to or nearly to the surface. They probably derive their supply from open connected channels in the limestone, for some wells that are near together are apparently interdependent. For example, it has been proved by the Logansport Ice and Cold Storage Company that when either of its four wells is pumped the water in the others is lowered. Strong drafts on the ice company's wells also lower the head in other neighboring wells.

CITY AND VILLAGE SUPPLIES.

Logansport.—Logansport, the county seat of Cass County, with a population in 1900 of 16,204, is situated in the valley bottom at the junction of Wabash and Eel rivers, at an altitude of about 600 feet

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above sea level. The waterworks, which are owned by the city, were built in 1875. Eel River is the source both of the water supply and of the power by which it is distributed, the power being developed by a dam built across the stream.

About half the population uses the city water, which is distributed by direct pressure through 33 miles of mains from 2 to 20 inches in diameter. These mains supply 202 fire hydrants and 3,220 taps, the total consumption being from 3,000,000 to 4,000,000 gallons a day.

Since the city water is derived from a surface source, it is very soft, contains little scale-forming material, and has the reputation among the railroads of being an ideal boiler water. For manufacturing and steaming it is superior to the limestone water obtained from the wells, but for drinking, used as it is in Logansport without filtration, it is less desirable. Eel River, like other surface streams in closely settled regions, is in constant danger of pollution. In periods of flood the unsatisfactory condition of the water is obvious, but there may be greater danger in the clearer water that is pumped into the mains during periods of low water in the streams. The installation of a filtration plant would greatly improve conditions here.

The 50 per cent of Logansport's inhabitants who do not use the city water depend on cisterns and private wells for their supply. The wells are 15 to 90 feet deep, dug or drilled, and obtain water either from gravels or from the underlying limestone, which is at most places found at less than 40 feet below the surface. In the past, shallow, open dug wells have been much used, but it is now recognized that they are very unsafe in an area that is so closely settled, hence most of them have been wisely abandoned for drilled wells, 40 to 60 feet deep, that penetrate the underlying rock and obtain from it safe, though hard, waters.

Royal Center.—Royal Center is a thriving town in the northwest corner of Cass County, with a population of about 1,000. A municipal waterworks system owned by the city has been installed and a well 6 inches in diameter and 280 feet deep has been drilled as a source of supply. This well, which derives its water from the "Niagara" limestone, has been tested and found to have a capacity of 15,000 gallons an hour. The water is pumped from the well to a 68,000-gallon wooden tank at an elevation of 90 feet. This elevation gives a domestic pressure of 40 pounds, but for protection from fire the water is pumped directly into the mains and a much higher pressure is thereby obtained. The system, with its 2 miles of 4 to 6 inch mains and its 72 services, supplies about one-third of the inhabitants of the city, the average daily consumption being about 25,000 gallons.

The remaining two-thirds of the people still use private wells, the greater number of which are 40 to 60 feet deep. The water supply for these wells comes from gravel beds in the till, and since these

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gravels are protected from pollution by the compact clay above them, they form safe reservoirs. Typhoid fever is therefore almost unknown in Royal Center.

Galveston.—Galveston, in the southeast corner of Cass County, stands about 20 feet above Deer Creek on a gently undulating till plain. The town supply is drawn from an 8-inch drilled well, 180 feet deep, owned by W. H. Sprinkle. At 63 feet below the surface this well enters the "Niagara" limestone, whence it procures its supply.

A pump with a capacity of 110 gallons a minute is operated by a gasoline engine which forces water into a 500-barrel tank that stands 50 feet above the ground. From this tank it is distributed to the users through 5 miles of 2 and 4 inch mains. Twenty-five hydrants are provided for fire protection, and direct pressure is used when needed. Nearly all the people in Galveston use the public supply, but there are a few private drilled wells, from 80 to 180 feet deep, one of which flows.

Walton.—Walton, 9 miles southeast of Logansport, with a population in 1900 of 498, has no waterworks system. All the local water supplies are drawn from wells, of which many types are represented, open dug wells predominating. The wells range in depth from 15 to 25 feet and they rarely fail, but those that stand near outhouses or other buildings are unsafe. In this village there are a few deeper drilled wells that enter rock at 60 to 100 feet below the surface and procure plentiful supplies of perfectly safe potable waters. (Analyses 18 and 19, p. 94.) Wells of this deeper type are strongly recommended.

Young America.—Young America is a flourishing and progressive village in the southwest corner of the county, 9 miles from the nearest railroad station. Until within a few years all water has been obtained from dug wells, but the tendency of late has been to sink deep-drilled wells. The village is very favorably situated to procure the deeper supplies, for excellent potable waters (analysis No. 20, p. 94) are found here in limestone at depths of 60 to 80 feet, and when tapped the waters rise to within 20 feet of the surface. Under these conditions all of the shallower wells should be abandoned, and when this step is taken typhoid fever should be much less prevalent than it is now.

Other communities.—A tabulated list follows of other communities in Cass County, with the conditions of water supply in each.

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Other village supplies in Cass County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Adamsboro	143	Wells, dug and drilled.	16	30	25	4	.....	Limestone.
Anoka	86	....do.....	16	120	20	90	16	Gravel and limestone.
Clymers	138	....do.....	20	80	30	.....	10	Gravel.
Deacon	40	....do.....	18	100	23	70	.....	Gravel and limestone.
Georgetown	100	Wells, drilled.....	10	47	40	4	.....	Limestone.
Hoover	105	Wells, driven and dug.	20	45	45	.....	.....	Gravel.
Lake Cicott	40	Wells, driven and drilled.	27	87	30	.....	.....	Sand.
Lincoln	170	Wells, dug and drilled.	15	115	20	56	8	Clay and limestone.
Lucerne	30	Wells, drilled and driven.	20	110	60	.....	20	Gravel.
Metea	35	....do.....	60	90	70	.....	15-30	Do.
New Waverley	280	Wells, driven, drilled, and dug.	10	60	15	8	12	Gravel and limestone.
Onward	175	Wells, dug and drilled.	9	112	16	80	9	Do.
Twelve Mile	100	Wells, driven, drilled, and dug.	12	120	80	280	.....	Gravel.

TYPICAL WELLS AND ANALYSES.

In the two following tables are given detailed information regarding typical wells in Cass County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in Cass County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Galls.*	*° F.*	
1	G. P. Dykeman	Anoka	120	Drilled	4	115	−15	Limestone	90	.....	.....	1
2	B. Castaldi	Dunkirk	80	...do.....	.....	80	.....	.....do.....	.....	.....	.....	21
3	W. H. Sprinkle	Galveston	190	...do.....	8	.....	−20	.....do.....	63	.....	.....	3
4	Pliny Morgan	.....do.....	.....	...do.....	.....	.....	+ 5	.....do.....	.....	20	52	4
5	J. W. Griffin	5 miles W. of Galveston.	100(?)	...do.....	2	.....	+ 3	.....do.....	.....	10	52	2
6	T. Saunders	Lake Cicott	75	...do.....	2	75	.....	Sand	.....	.....	.....	...
7	F. M. Million	.....do.....	30	Driven	1¼	30	.....	.....do.....	.....	.....	.....	5
8	A. V. Watkins	Lincoln	115	Drilled	4	115	−16	Limestone	56	.....	.....	...
9	Logansport Ice and Cold Storage Co.	Logansport	600	...do.....	8	100	0	.....do.....	2	.....	.....	...
10	.....do.....	.....do.....	104	...do.....	8	100	0	.....do.....	2	.....	.....	8
11	City of Logansport.	Riverside Park	447	...do.....	8	447	+21	.....do.....	.....	1	54	7
12	.....do.....	Electric-light plant.	380	...do.....	8	370	+ 3	.....do.....	8	½	.....	...
13	John W. Kennedy.	Logansport	1,606	...do.....	6	.....	+	.....do.....	25	.....	.....	...
14	J. S. Kline	3½ miles NE. of Logansport.	101	...do.....	3	100	−50	Gravel	.....	.....	.....	9
15	Northern Indiana Insane Asylum.	Long cliff	618	...do.....	8	.....	+	Limestone	9	2	.....	12
16	John Winn	Lucerne	61	...do.....	2	60	.....	Gravel	.....	.....	.....	13
17	D. J. Forgy	New Waverly	18	Driven	1¼	18	.....	.....do.....	.....	.....	.....	14
18	Daniel Moon	1 mile S. of Onward.	12	Dug	.....	.....	+ 3	.....do.....	.....	.....	.....	15
19	City waterworks	Royal Center	290	Drilled	6	280	− 6	Limestone	.....	.....	.....	16
20	Schoolhouse	Twelve Mile	130	...do.....	.....	.....	.....	Gravel	.....	.....	.....	17
21	W. S. Kepner	Walton	78	...do.....	4	.....	−10	Limestone	70	.....	.....	18
22	Uriah Starry	.....do.....	106	...do.....	4	.....	−10	Sandstone	81	.....	.....	19
23	Public well	Young America	65	...do.....	4	65	−20	Limestone	60	.....	.....	20
24	Dr. N. W. Cody	Logansport	87	...do.....	5	.....	.....	.....do.....	.....	.....	.....	6

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Mineral analyses of waters in Cass County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in rec. of wells.
1	G. P. Dykeman.	Anoka.....	Drilled well, 120 ft. by 4 in.	H. E. Barnard	1907.....	Limestone	....	2.4	.....	94	31	.....	.....	0.0	305	12	8.0	0.40	.....	20	392	1
2	J. W. Griffin....	5 miles W. of Galveston.	Drilled well, 100 ft. by 2 in.	.....do.....	1907.....	.....do.....	....	1.6	.....	44	28	.....	.....	.0	264	0.0	4.0	.10	.001	2	346	5
3	W. H. Sprinkle..	Galveston.....	Drilled well, 190 ft. by 8 in.	.....do.....	Oct., 1907	.....do.....	....	.3	.....	69	28	.....	.....	.0	324	318	3.0	.10	.00	19	390	3
4	Pliny Morgan....	.....do.....	Drilled old gas well....	.....do.....	1907.....	.....do.....	....	.10	.....	106	30	.....	.....	.0	320	263	3.0	.001	.01	9	562	4
5	F. M. Million...	Lake Cicott...	Driven well, 30 ft. by 1¼ in.	.....do.....	Nov., 1907	Sand.....	....	.1	.....	66	25	.....	.....	.0	206	18	12.0	2.50	.001	9	340	7
6	Dr. N. W Cody.	Logansport...	Drilled well, 87 ft. by 5 in.	.....do.....	....do.....	Limestone	....	.5	.....	94	34	.....	.....	.0	306	18	4	.10	.002	4	378	24
7	Riverside Park..	.....do.....	Drilled well, 447 ft....	R. B. Dole....	Aug., 1907	.....do....	12	.02	1.8	87	54	304	26	Tr.	416	85	514	.00	.....	.....	1,274	11
8	Logansport Ice and Cold Storage Co.	.....do.....	Drilled well, 104 ft. by 8 in.	.....do.....	....do.....	.....do....	18	.08	112	147	46	101	11	.0	411	166	200	.4	.....	.....	906	10
9	J. S. Kline.....	3½ miles E. of Logansport.	Drilled well, 101 ft. by 3 in.	H. E. Barnard	1907.....	Gravel.....	....	1.4	.....	112	39	.....	.....	.0	348	57	8	2.50	.005	9	490	14
10	D. D. Dykeman.	3 miles E. of Logansport.	Spring.....	.....do.....	1907.....	.....	....	.2	.....	106	26	.....	.....	.0	499	42	8	4.0	.005	9	414	...
11	Northern Indiana Insane Asylum.	Long cliff.....	Wells.....	.....	1907.....	Limestone	39	5.0	4.6	95	34	13		341	.....	53	31	.....	.....	.....	.....	...
12	.....do.....	.....do.....	Drilled well, 618 ft. by 8 in.	H. E. Barnard	1907.....	.....do.....	....	1.6	.....	113	62	.....	.....	.0	360	36	860	.10	.....	9	1,992	15
13	John Winn.....	Lucerne.....	Drilled well, 61 ft. by 2 in.	.....do.....	1907.....	Gravel.....	....	1.0	.....	113	35	.....	.....	.0	350	24	56	.0	.001	2	542	16
14	D. J. Forgy.....	New Waverley	Driven well, 18 ft.....	.....do.....	1907.....	.....do.....	....	1.0	.....	121	35	.....	.....	.0	285	60	26	10	.003	13	464	17
15	Daniel Moon....	1 mile S. of Onward.	Open well, 12 ft.....	.....do.....	1907.....	.....do.....	....	1.2	.....	100	32	.....	.....	.0	346	0.0	3	.0	.001	2	384	18
16	Public supply...	Royal Center..	Drilled well, 290 ft. by 6 in.	.....do.....	1907.....	Limestone	....	0.5	.....	54	29	.....	.....	.0	305	0.0	5	.20	.001	2	354	19
17	Schoolhouse.....	Twelve Mile..	Drilled well, 130 ft....	.....do.....	1907.....	Gravel.....	....	2.4	.....	58	17	.....	.....	.0	216	37	7	.0	.00	9	268	20
18	W. S. Kepner...	Walton.....	Drilled well, 78 ft. by 4 in.	.....do.....	1907.....	Limestone	....	1.0	.....	106	33	.....	.....	.0	336	79	4.0	.0	.20	12	402	21
19	Uriah Starry....	.....do.....	Drilled well, 106½ ft. by 4 in.	.....do.....	Oct., 1907	Sandstone	....	1.6	.....	103	27	.....	.....	.0	318	126	7.0	.30	.00	33	292	22
20	Public well.....	Young America.	Drilled well, 65 ft. by 4 in.	.....do.....	1907.....	Limestone	....	3.6	.....	34	35	.....	.....	.0	252	0.0	14	.05	.001	4	408	23
21	B. Castaldi.....	Dunkirk.....	Drilled well, 80 ft....	.....do.....	Nov., 1907	.....do.....	....	.01	.....	131	28	.....	.....	.0	253	84	70	.60	.001	9	490	22

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CLINTON COUNTY.

SURFACE FEATURES AND DRAINAGE.

Clinton County, in the western tier of the counties here discussed, has Carroll and Howard counties on the north, and Boone on the south. With an area of 402 square miles, it had in 1900 a population of 70 inhabitants to the square mile. Frankfort, the county seat, is 40 miles northwest of Indianapolis.

Practically the whole of the county, which lies on the plateau between Wabash and White rivers, is to be classed as uplands. The surface slopes from an elevation of 900 feet above sea level in the southwest quarter to less than 700 feet in the valley of Middle Fork of Wild Cat Creek, where it crosses the west county line. Through the whole county the rock is overlain by a thick layer of glacial till, which has entirely obscured the topography of the underlying rock. The present relief is entirely due to the form given to the surface deposits by the glacier and to the subsequent shaping of the materials by erosion. The greater part of the county is a level till plain, although in the north half there are several small areas of a few square miles each which are occupied by morainal drift, and in these areas the surface is less regular and the relief greater than in equal areas of till surface, although the moraines are nowhere very prominent topographic features.

Clinton County has no large streams. Several creeks have their sources here, but only one, South Fork of Wild Cat Creek, flows across the county from a source outside of it. The valley of this creek north of Michigantown is merely a shallow dip in the till plain, but becomes gradually deeper toward the west. Middle Fork of Wild Cat Creek rises in the northeast corner of the county, flows northwest into Carroll County, and then curves southwest to reenter Clinton County and flows across its northwest corner. All the other creeks are small and have valleys that lie only a few feet below the plain.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

As there are no large, well-developed valleys, the alluvial deposits of the county are unimportant. In the lower courses of Middle and South Forks of Wild Cat Creek there are narrow flood plains of alluvium, and these deposits, even in small areas, are good water bearers. The water lies near the surface and the open gravels yield their waters readily to wells. Driven wells are the cheapest and most satisfactory type for use in alluvium, but care should be taken not to drive the wells through the alluvium into the underlying till for the gravels are not of great depth in the small valleys.

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The moraines of this county are patchy in distribution (Pl. I) and occur only as rather thin deposits on top of the till. Wells in them locally find water above the till, but in most places it is necessary to go through the morainal beds into the till. Driven or drilled wells are commonly employed for this purpose.

As shown in Plate I, the till occupies most of the surface of the county and is actually continuous over it, though covered locally by moraines. In the southwest corner of the county the rock is within 125 to 150 feet of the surface, but throughout the county the till probably averages 250 feet thick, and at Frankfort it is 275 feet and at Kirklin 300 feet to the underlying rock (Pl. II). In this county the gravel beds of the till are in many places far below the surface or are too thin to supply much water. Consequently most of the wells are dug or open and are supplied by seepage from the close-textured till. Such wells, if dug below the level of the water table during the dry seasons, will usually supply enough water for family use. For the use of stock or for manufacturing purposes such wells are inadequate. Large users of water must supply themselves from surface waters or put in deep drilled or driven wells, which are commonly successful in reaching gravel or sand beds. At Frankfort large quantities of water for the city supply are drawn from open gravel beds in the till.

CONSOLIDATED MATERIALS.

The outcrops of three great groups of rocks extend across this county beneath the surface deposits, and occur as belts running from northwest to southeast (Pl. III). At the east edge of the county the uppermost rocks are the Devonian limestones, the oldest of the three series. Next younger and uppermost in the central and northwest portions is the New Albany shale. In the extreme southwest corner of the county the highest rocks are the shales of the "Knobstone" group, of Mississippian age. These rocks have all been described in previous parts of this report. None of them furnishes water to the wells in Clinton County.

ARTESIAN AREAS.

At Alhambra Lake, one-quarter mile south of the court-house at Frankfort (Pl. IV, No. 15), there is a single flowing well. As this well is below the surface of the lake, there was no opportunity to determine its yield. In 1884 there were five flowing wells at this lake, one of which yielded 96 gallons per minute, and the area in which flowing wells could be obtained was at that time much larger than it is now. Flowing wells could then be obtained all along the creek, and the water at the city pumping station would rise 6 feet above the surface. Alhambra Park was for many years a thriving resort, with boating and bathing in the lake. The artesian waters

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were all obtained from a gravel bed, 65 feet below the surface, and the head is from the uplands near by.

Area 16 extends from Manson eastward for about 4 miles along the creek. (Pl. IV, No. 16.) At Manson the wells are almost all driven into gravel in the till to depths of 35 to 45 feet, and although none of them flows constantly several flow at the surface in wet weather. One flowing well is reported two miles south of Frankfort.

Two miles north of Kirklin there is a single flowing well in the lowlands (see Pl. IV, No. 17), driven into gravel at 40 feet, from which the water will rise 9 feet above the surface. The artesian conditions are local, though probably other flows could be procured in the neighborhood, on ground as low as that near the existing well. The water comes from the higher ground not far away.

There are a number of flowing wells along the valley of Middle Fork of Wild Cat Creek, north of Boyleston and Hillisburg and in the vicinity of Michigantown. (Pl. IV, No. 18.) The strongest of these, 1 mile north of Michigantown, is driven over 100 feet through the till into gravel and is said to flow with a 1-inch stream. All the wells of this area are in the lowlands, and wells on higher ground striking the same gravel beds, would not flow.

In the vicinity of Moran there are two flowing wells (Pl. IV, No. 19), one of which, on the property of N. E. White & Co. (No. 15, p. 100), is a dug well 19 feet deep. It obtained a flow of about 1 gallon per minute from a gravel bed, and a pump is used to raise the water to a convenient height. The second artesian well, 1½ miles west of Moran (No. 16, p. 100), is a driven well 60 feet deep and flows almost enough to fill a 2-inch pipe. Though the above wells are some distance apart and obtain their flows from different depths, they are both in the till and have been classed as in a single artesian area.

Along the valley of North Fork of Wild Cat Creek, between Forest and the county line, and in the valley of the tributary east of Sedalia, there are five or six artesian wells (Pl. IV, No. 20), all of which are driven into gravel beds in the till, at depths of 35 to 100 feet. The waters from these gravels have just enough head to give flows in the valleys. The conditions for flows seem to be favorable along much of this valley, if the wells are located on low enough ground. Records of these wells are given on page 100.

CITY AND VILLAGE SUPPLIES.

Frankfort.—Frankfort, the county seat, is the only city in Clinton County which has a public water supply. It lies 3 miles southwest of the geographic center of the county, and its population in 1900 was 7,100. The waterworks of this city are the property of the Frankfort Water Works Company, and the water is drawn from 12 drilled

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wells, 6 inches in diameter. One well penetrates to a depth of 208 feet into an 8-foot stratum of sand, and formerly flowed with a head 6 feet above the surface. For the last twenty years this head has gradually become lower, and the well has long since ceased to flow. The other wells are about 82 feet deep, and a gravel bed is reported at 55 feet. The water from this gravel enters the well and formerly rose under artesian pressure almost to the surface. The head is now 20 feet below the surface. Although the wells are situated in the center of the town, the gravel bed from which the water comes is protected above by impervious blue clay and hardpan, and should be safe from contamination. There has been some complaint that the water is turbid, but on the whole the supply seems to be very good. Direct pressure is used, the water being pumped from a 400,000-gallon reservoir into the mains. There are now over 16 miles of mains of thin wrought iron lined with concrete. In 1907 the company was engaged in laying 7 miles of additional mains, part of this work being already completed at the time the town was visited. There are about 2,000 services, and 75 per cent of the people of Frankfort use this water, requiring about 1,000,000 gallons per day.

Many families in this city still use water from private wells, most of which are driven to depths of 30 to 60 feet and obtain good water from the gravels. Unfortunately many shallow dug wells are still in use. Some of these, when examined, showed strong evidences of pollution by their appearance and odor. Cesspools and wells were found side by side and the one very evidently was in direct connection with the other. Analyses 3 and 4 (p. 101) are of the waters of two dug wells that show evidences of the presence of sewage.

From water-well borings and from the record of a well sunk for gas the geologic section at Frankfort has been found to be as follows:

Log of well drilled for gas at Frankfort.[a]

	Feet.
Clay and hardpan with some gravel	55
Gravel	32
Till	113
Sand	8
Till	70
Niagara limestone and shale	380
Trenton [meant for Clinton]	10
Hudson River and Utica shale	400
Trenton limestone	260
	1,328

Colfax.—Colfax, a village of 768 inhabitants (1900), is in the southwest corner of the county. It has no public water system and the water used is drawn from private wells. Most of these are open wells, 15 to 25 feet deep, though a few wells, driven and drilled to

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 245.

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depths of 40 to 50 feet are used. The water rises within 6 or 8 feet of the surface, but no flows have been found. The deeper wells go through the till into gravels and get pure, safe water. An analysis of water from a depth of 102 feet is No. 2 (p. 101). The dug wells are very likely to become polluted, and are not safe to use when located in a town and surrounded by barnyards and privies.

Kirklin.—Kirklin, in southeastern Clinton County, is situated on the till plain about a mile south of Sugar Creek. The water supply is drawn from dug and driven wells and cisterns, and no public water supply has been installed. Most of the wells in use are dug wells less than 30 feet in depth. There are, however, a number of driven wells, the deepest of which extend to more than 100 feet below the surface. None reach bed rock, the water being obtained from gravel beds. Under the town there are three gravel beds which may be encountered, the first at 15 to 20 feet, the second at 50 to 60 feet, and the third at 100 to 115 feet. The shallowest of these is the one most commonly drawn upon, but the water at this depth is not safe from pollution. From time to time, there has been considerable typhoid fever in this town, doubtless due to the use of shallow wells. The water in the second gravel is very much safer, and that from the third gravel is subject to but very slight chance of becoming contaminated. Analyses of the third gravel waters are Nos. 7 and 8 (p. 101).

Rossville.—Rossville, in the northwest part of the county, is on a rolling plain. The source of supply is from wells, which are about equally divided between the dug and driven types. The most common depth for wells is 30 feet, though some are shallower and some deeper. The water is obtained from gravel beds which occur at about 25 to 30 feet, and at 40 feet. The general health of the town has been good, but the 40-foot wells are recommended as a much safer source of supply than the shallower ones. An analysis of water from a depth of 40 feet is No. 12 (p. 101).

Mulberry.—Mulberry, 8 miles northwest of Frankfort, is supplied almost altogether from dug wells, which range from 12 to 30 feet in depth and in which the water from gravel beds rises within 12 feet of the surface. Two deeper wells were sunk but were unsuccessful, as both encountered quicksand at a depth of about 100 feet and had to be abandoned. As the shallow gravel beds seem to be the only available source of supply, it would be advisable to sink driven wells to these gravels. These wells, if properly cased, would be superior to the loosely walled dug wells, because water could enter them only from the bottom. The open wells receive water through their walls from all depths and are subject to pollution from many sources.

Other communities.—A list of other villages with particulars regarding their water supply is given in the following table.

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Other village supplies of Clinton County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Beard	34	Wells, dug and driven	20	101	25	.....	−20	Gravel.
Boylestown	120	do	15	45	33	.....	−15	Do.
Edna Mills	72	do	10	18	15	.....	− 5	Do.
Forest	286	do	15	100	30	225	−10	Do.
Greetingsville	.....	do	20	110	40	.....	.....	Do.
Hillisburg	268	do	15	64	40	.....	−5 to −10	Do.
Jefferson	100	do	20	82	26	.....	.....	Do.
Manson	175	Wells, driven	35	45	40	.....	0 to − 3	Do.
Michigantown	417	Wells, dug and driven	19	125	23	.....	0 to −12	Do.
Middlefork	119	do	20	70	60	.....	+4 to − 6	Do.
Moran	200	do	15	60	25	.....	0 to − 3	Do.
Pickard	150	Wells, dug, driven, and drilled.	15	150	35	.....	−13	Do.
Scircleville	167	Wells, dug and driven	30	135	40	.....	−12	Do.
Sedalia	300	do	15	80	20	.....	−12	Do.

TYPICAL WELLS AND ANALYSES.

In the two following tables are given detailed information regarding typical wells in Clinton County and analyses of their waters. The last column of each table gives the numbers of identical wells in the other table.

Records of typical wells in Clinton County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Analysis No.
			Ft.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Gals.*	
1	G. T. Myers	1 mile SW. of Boylestown.	35	Driven	1½	35	−15	Gravel	.....	.....	1
2	Wm. Powers	Colfax	102	Drilled	2	80	− 8	do	.....	.....	2
3	George Dukes	do	216	do	2	86	− 6	do	.....	.....	.....
4	W. H. Davis	Forest	100	do	8	.....	−	Limestone	225	.....	.....
5	Frankfort Water Works Co.	Frankfort	82	do	6	50	−20	Gravel	.....	.....	.....
6	Milton Oliver	do	15	Dug	.....	15	.....	do	.....	.....	3
7	D. A. Coulter	do	20	do	.....	.....	.....	do	.....	.....	4
8	James I. Miller	Jefferson	83	Driven	.....	.....	−18	do	.....	.....	6
9	Bert McKinney	Kirklin	52	do	2	50	.....	do	.....	.....	.....
10	R. C. Gorham	do	102	do	2	100	−16	do	.....	.....	7
11	Marion Anderson	2 miles N. of Manson.	80	do	1½	80	−12	do	.....	.....	.....
12	M. E. Miller	Michigantown	120	do	2	.....	−14	do	.....	.....	.....
13	F. Ridenow	Middlefork	65	do	1½	65	+ 3	do	.....	6	9
14	John Revis	¾ mile N. of Middlefork.	65	do	1¼	30	+	.....	.....	.....	.....
15	N. E. White & Co.	Moran	19	Dug	.....	19	+ 2	Gravel	.....	1	10
16	Markwood Slipher	1½ miles W. of Moran.	60	Driven	2	60	+ 3	do	.....	.....	.....
17	Dr. I. S. Earhart	Mulberry	21	Dug	.....	21	−15	do	.....	.....	11
18	Rossville Bank	Rossville	40	Drilled	1¼	40	−30	do	.....	.....	12
19	Charles Fulkerson	Sec. 25 T. 21, R. 1 E.	40	Driven	2½	.....	+ 9	do	.....	2½	.....
20	H. F. Cheney	Sec. 24, R. 1 W., Owen township.	46	do	2½	40	+ 7	do	.....	12	.....
21	John Kemner	Sedalia	46	do	3	.....	−20	do	.....	.....	.....
22	Carl Peitsch	do	90	Drilled	2	88	−37	do	.....	.....	.....
23	Simms & Ashpaugh.	Scircleville	115	do	3	115	.....	do	.....	.....	13

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Mineral analyses of waters in Clinton County.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Parts per million.																
							Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	G. T. Myers	1 mile SW. of Boylestown.	Driven well, 35 ft. by 1¼ in.	H. E. Barnard.	Oct. 1907	Gravel		2.2		61	27			0.0	344	55	4.0	0.30	0.0	33	398	1
2	Wm. Powers	Colfax	Well, 102 ft. by 2 in.[a]	do	do	do		2.0		111	24			.0	358	96	9.0	.0	.001	0	448	2
3	Milton Oliver	812 First street, Frankfort.	Open well, 15 ft.	do	do	do		4.8		133	41			.0	402	158	20.0	.0	.0	33	614	6
4	D. A. Coulter	908 Second street, Frankfort.	Open well, 20 ft.	do	do	do		1.2		116	39			.0	436	269	39.0	.20	.06	7	706	7
5	Lake Erie and Western R. R.	Hillisburg	Well, 265 ft.	L. F. & W. R. R.	Sept. 1903			7.7		82	32	13		202		21	4.8					
6	Jas. I. Miller	Jefferson	Well, 83 ft.	H. E. Barnard.	Oct. 1907	Gravel		.8		79	6.5			.0	267	85	7.0	.00	.001	15	370	8
7	R. C. Gorham	Kirklin	Well, 102 ft. by 2 in.	do	do	do		2.0		71	24			.0	302	60	4.0	.00	.000	19	419	10
8	J. W. Wills	do	Well, 51 ft. by 2 in.	do	do			1.6		34	24			9.0	202	32	5.0	.00		0	314	
9	Fred Ridenow	Middlefork	Well, 65 ft. by 1¼ in.	do	do	Gravel		.6		64	20			.0	320	38	12	.50	.000	6	414	13
10	N. E. White & Co.	Moran	Open well, 19 ft.	do	do	do		1.0		103	40			.0	403	66	11	.00	.001	19	512	15
11	Dr. I. S. Earhart	Mulberry	Open well, 21 ft.	do	Sept. 1907	do		.0		126	30			.0	347	107	67	2.00	.10	0	528	17
12	Rossville Bank	Rossville	Well, 40 ft. by 1¼ in.	do	Oct. 1907	do		1.0		116	21			.0	345	210	15	.00	.001	19	536	18
13	Simms & Ashpaugh	Scircleville	Well, 115 ft. by 3 in.	do	do	do		.6		34	18			.0	286	60	6.0	1.5	.001	33	340	23

[a] Water at 80 feet.

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ELKHART COUNTY.

SURFACE FEATURES AND DRAINAGE.

Elkhart County, in the northeastern corner of this area and at the north edge of the State, is rectangular in outline, measuring 21 miles from east to west and somewhat more than 22 miles from the north to the south border. The total area is approximately 470 square miles and the average population (1900) 96 to the square mile. The county seat, Goshen, is near the center of the county, and lies 92 miles east of Chicago and 125 miles north of Indianapolis.

Elkhart County has a topography of great diversity. From St. Joseph River north to the county line, and for some distance south of that stream, the country is low and has very slight relief, and this flat area extends to the southeast corner of the county, along the valley of Elkhart River (Pl. I). At the edges of the flat area, moraine ridges rise sharply from the plain. South of Bristol the highest points of the moraine are over 200 feet above the flat and reach an altitude of over 1,000 feet above sea level. No other county in the area here treated has so great a range of elevation as Elkhart County, the surface of which rises from less than 750 in the valley of St. Joseph River to over 1,000 feet at a number of points. The southwest corner, though covered by glacial deposits, consists of a rolling plain of low relief, and is not so high as the moraine-covered areas. The surface features of the county are entirely due to the form of the unconsolidated materials, as only in the deepest valley, that of St. Joseph River, have borings reached rock, which here lies 120 to 160 feet below the surface. In the high moraines the surface deposits have doubtless a thickness of 250 to 400 feet.

Elkhart County lies wholly within the basin of St. Joseph River, which enters the county from the north, near Bristol, and, flowing somewhat south of west as far as Elkhart, turns west to enter St. Joseph County. The stream occupies a rather narrow channel in a very wide valley of alluvial materials. The principal tributary is Elkhart River, which flows across the county from southeast to northwest. Like that of the St. Joseph, its valley is wide and contains extensive alluvial beds. Bauge Creek, Pine Creek, and Little Elkhart River are other tributaries to the St. Joseph from the southeast. It receives no important branches from the north.

There are about a score of small lakes in the county which occupy depressions in the moraines. The largest is Simonton Lake, 4 miles north of Elkhart, and its area is but little more than one-half square mile.

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GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Alluvial deposits here have a considerable area and are of great importance as water producers. They lie on both sides of St. Joseph River, the alluvial flat ranging from 3 to 5 miles in width. Alluvium also occurs in a strip from 1 to 3 miles wide along the Elkhart River valley. At Elkhart wells penetrate about 34 feet of gravel and sand before they strike the underlying glacial clay. At Bristol the deepest wells have been sunk only 30 feet and have failed to reach the bottom of the alluvium. At Goshen, which is near the edge of the alluvial plain, the gravels are thinner but increase in depth toward the valley center.

Bordering the terminal moraines and occupying the gentler slopes below them there are in some places plains of alluvial material of different origin from the above-described valley deposits. These are outwash plains of the kind described on page 31.

Underground water is abundant throughout almost the entire alluvial area, for rainfall is rapidly absorbed at the surface and the relief is so slight that the waters are not readily drained from the lowlands, while the open and porous character of the beds makes the water readily available. The very fact that deep wells are absent in these alluvial areas is a sufficient indication that satisfactory supplies can be obtained at moderate depths. Driven wells from 15 to 30 feet deep are commonly used, and for household or farm uses these have proved satisfactory.

The moraines have a greater surface area than any other class of deposits in Elkhart County, occupying about one-half the surface. They all lie south of St. Joseph River, and there is a sharp topographic break between the alluvial plain along this river valley and the ridgelike moraines. Much of the surface is strewn with large and small bowlders. Driven or drilled wells are preferred in these deposits, as with them it is possible to go to greater depths if water is not found near the surface. The wells range in depth from 15 to 200 feet and the best supplies of water are usually found in gravel or sand beds in the clay.

It is probable that the till underlies all the other surface deposits of the county and exists as a continuous sheet below them and above the rock, although it occupies the surface only in the southwest corner of the county (Pl. I). There the topography is that of a rolling plain, broken only by the shallow valleys of small streams. Few surface cuts show gravel beds in the till, but the drill commonly reveals their presence at some depth. The clayey portions of the till yield water slowly to wells, and to procure satisfactory quantities of water it is commonly necessary to sink open wells of large surface area from 15 to 40 feet in depth to obtain the seepage from the clay. Driven and drilled wells are generally successful in procuring abundant water in beds of gravel.

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CONSOLIDATED MATERIALS.

A study of the position, succession, and character of rock beds in this county explains why the rock beds here have never been utilized as a source of water supplies and demonstrates that these rock waters can never be exploited to any great extent. A well boring at Elkhart (Pl. I), in the lowest portion of the county, shows the surface deposits to be 122 feet deep. Below this there is a thickness of 429 feet of shales which yields no water. It is therefore 551 feet down to the first rock formation, the "Corniferous" limestone of the well drillers, which might be expected to yield abundant supplies of water, and even this water would be likely to contain objectionable quantities of sulphur and salt. In the higher portions of the county, where the glacial deposits are thicker, an additional 100 or even 200 feet must be added to the above depth at which limestone will be encountered. The cost of such deep borings will prevent them from ever becoming common, and underground waters must be obtained from the surface materials.

ARTESIAN AREAS.

In and about the city of Elkhart, along the lowlands of St. Joseph River, is an area in which about a dozen flowing wells have been obtained (Pl. IV, No. 21), the best known of which are at Island and McNaughton parks. These wells are reported to obtain the flowing waters from sand and gravel beds at depths of 60 to 90 feet. As shown in the well log on page 105, the water-bearing beds are protected from pollution from above by many feet of close-grained blue till. Flows can be obtained only in the bottom lands, where the waters will rise 2 or 3 feet above the surface. On higher ground the same artesian waters may be encountered by wells, but the head is sufficient to carry the water only a few feet above the level of the river. An analysis of water from the Island Park flowing well is No. 11 (p. 109).

Area 22 (Pl. IV) includes the low ground in and near Wakarusa, where there are 10 or 15 flowing wells and a large number in which the water is under artesian pressure but does not rise to the surface. The flows are all obtained from a gravel bed lying from 28 to 40 feet below the surface of the till. The wells are all driven, and the pipe most used is 1¼ inches in diameter. None of the wells gives a large flow, but the yield, from a fraction of a gallon to 5 gallons per minute, continues throughout the year. The temperature of the wells tested was 51° F. An analysis of the water from one of these wells is No. 21 (p. 109).

CITY AND VILLAGE SUPPLIES.

Elkhart.—Elkhart lies at the junction of Elkhart and St. Joseph rivers and in 1900 had a population of 15,184. The public water system, installed in 1884, is owned by the Elkhart Water Company,

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a private corporation. The water is drawn from three dug wells, 34 feet deep, two of which are 40 and the other 30 feet in diameter. The materials penetrated were sand and gravel, clay being encountered at the bottom. The wells, situated at the edge of the town, in a grove owned by the water company, are a considerable distance from the nearest dwellings and outhouses, and the supply seems to be a very satisfactory one. The city health officer reports that no case of typhoid fever has ever been traced to the city water. There is some objection, however, to a yellowish color which the water has after a fire has necessitated more than the ordinary pumping. The extra pressure tends to loosen deposits of iron which have formed in the mains, and this discoloration of the water lasts for a few hours. Up to the present time the supply from the wells has been sufficient for all purposes. The company has an emergency connection with Christiana Creek, so that in case of fire an additional supply can be obtained.

Direct pressure is used to supply about 33 miles of mains, which range from 6 to 24 inches in diameter. There are 3,320 taps, and it is estimated that about one-fourth of the people of Elkhart use this water, from 2,000,000 to 6,000,000 gallons per day being required to meet the demand.

About three-fourths of the people of this city still use private wells, most of which are driven, though many dug wells are still in use. The common depth from which water is drawn is 25 feet, or practically the same depth as the city wells, but the waters of private wells are more likely to become contaminated, for many of them are located near houses where kitchen slops are thrown out, and are often close to dug privy vaults. In the open-textured gravels and sands the liquids from these quickly penetrate to the ground-water table and become a part of the water supply. It is probable that safer waters could be secured from beds of gravel in the underlying till. From a deep boring for gas and from shallow well records, the following succession of beds has been determined for this vicinity:[a]

Log of well drilled for gas at Elkhart.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, etc.	5	5
Sand and gravel	29	34
Blue clay	88	122
Subcarboniferous gray shale	213	335
Hamilton blue shale	215	550
Corniferous limestone.		

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 242.

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Goshen.—Goshen lies on Elkhart River, near the center of the county. The public waterworks, built in 1880, are owned by the city, and the water is drawn from Rock Run and from two dug wells, 24 and 36 feet deep and 24 and 40 feet in diameter. They are dug through gravel, the walls being cemented, so that water can enter only from the bottom. The water from these wells is unsatisfactory. One of them is situated near the gas plant, and the water is covered with a thick, greasy scum and has a decided odor. Part of the city water comes from Rock Run, which flows for more than a mile through the edge of the town before it reaches the waterworks. There are many dwellings, barns, and outhouses along its course, and pollution from some of these sources is almost certain.

The city water is pumped by steam pumps to a standpipe 146 feet high, from which the water is distributed by gravity to 25 miles of mains ranging from 4 to 20 inches in diameter. An average of 1,500,000 gallons per day is needed to supply 1,800 services and 292 fire hydrants. In case of fire the standpipe is cut off and direct pressure is used.

The city has spent large sums of money in trying to obtain well water at the city plant. It is reported that $70,000 was spent in completing one dug well.

In the south part of the town the supply of underground water is very abundant. All driven wells have encountered plentiful waters at depths of 30 feet or less, and excavations for buildings are difficult on account of the inflow of ground waters. A fine city supply could be obtained by drilling shallow wells into the gravel a little distance beyond the settled portion of the town. An analysis of water from these gravels is No. 16 (p. 109).

About 20 per cent of the people of this city use private wells for domestic purposes, and a number of manufacturing establishments also have their own wells, most of which are driven, though there are still a few dug wells in use. All penetrate into gravel, and they range in depth from 18 to 90 feet. No water wells strike bed rock, for the record of an old gas boring shows that the rock here lies 165 feet below the surface. The log of this well is as follows:[a]

Log of well drilled for gas at Goshen.

	Feet.
Drift	165
Shale, Subcarboniferous and Devonian	308
Corniferous limestone	60
Water lime	32
Niagara limestone	728
Hudson River limestone and shale	307
Utica shale	215
Trenton limestone	239
	2,054

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 246.

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Nappanee.—Nappanee owns its own waterworks, the water for which is drawn from three drilled wells 160 feet deep, two 6 inches and one 12 inches in diameter. The town is situated on a rolling till plain and the waters are found in gravel beds below the till. The water is pumped by steam to a 75,000-gallon tank 116 feet high, from which it is distributed by gravity. There are 4 miles of 8, 6, and 4 inch mains and 315 taps, and about half of the people use this water.

Besides the public supply there are many private wells in Nappanee. Most of them are driven, but some are drilled and a few dug. Only the dug wells are shallow and receive the water by seepage from the till, while the driven and drilled wells are 60 to 120 feet deep, the common depth being about 70 feet. The water comes from gravel beds, and for domestic uses the supply seems to be an admirable one.

Wakarusa.—Wakarusa, on a rolling till plain 10 miles southwest of Goshen, has no public water supply. The wells are driven and drilled and range in depth from 15 to 165 feet. The most common depth is 35 feet, and all the wells enter gravel. There are many flowing wells in the town which afford an excellent supply (Nos. 18, 19, 20, p. 108). An analysis of the water from one of these flowing wells is No. 21 (p. 109).

Middleburg.—Middleburg is situated on an alluvial plain at the base of a very high, steep moraine ridge. Almost every family has its own private driven or drilled well, and there is no public supply. As a result of the topographic situation of this town the conditions for obtaining wells differ greatly in short distances. In the alluvium it is rarely necessary to drive a well more than 30 feet deep to obtain plenty of water, but on the moraine a depth of 150 feet is in some places required before a satisfactory supply is obtained.

Bristol.—In Bristol, on the great St. Joseph River alluvial plain, the wells are all driven and all have reached unfailing water. The deepest well in town is but 25 feet deep, and the depth of the alluvium at this place is not known. The water rises in the wells within 10 or 12 feet of the surface, and even the driest seasons fail to lower the head to any noticeable extent.

Millersburg.—Millersburg is situated on a low moraine in the southeast part of the county. All the wells here are driven, usually to a depth of about 28 feet. The deepest well in town is 65 feet deep and does not reach rock. The water supply comes from a gravel bed in the moraine and rises within 18 feet of the surface.

Rural districts.—In the rural districts the conditions vary with the material at the surface. In alluvial areas driven wells are largely used and are generally not sunk to depths of more than 30 feet. Water is more difficult to obtain in the morainic deposits, and driven or drilled wells, ranging in depth from 15 to 200 feet, are most common, the water being usually found in gravel in the drift. In

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those portions of the county where the till comes to the surface the conditions for wells are least favorable. Here dug wells are most common, and the water is yielded to them slowly by seepage. Deep drilled wells, almost without exception, encounter water-bearing gravel beds in the till if they reach sufficient depths.

Other communities.—A list of other villages in Elkhart County, with particulars of their water supply, is contained in the following table:

Other village supplies of Elkhart County.

Town.	Population (1900).	Source.	Depth of wells.			Head below surface.	Character of water beds.
			Least.	Greatest.	Common.		
			Feet.	*Feet.*	*Feet.*	*Feet.*	
Boston	181	Wells, driven	10	20	15	3-8	Gravel and sand.
Dunlaps	33	do	18	28	25	14	Do.
Foraker	52	Wells, driven and drilled.	60	125	80		Gravel.
Jamestown	50	Wells, driven	25	65	50	6-12	Do.
Locke		do	25	110	65		Do.
New Paris	456	do	10	50	15	8	Gravel and sand.
South West	52	Wells, driven and drilled.	45	135	45		Gravel.
Vistula	141	Wells, driven	20	30	25	8	Gravel and sand.
Waterford		do	10	20	16	8	Do.

TYPICAL WELLS AND ANALYSES.

In the following two tables are given the records of typical wells in Elkhart County and analyses of their waters. The last column in each table gives numbers referring to identical wells in the other table.

Records of typical wells in Elkhart County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing material.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Ft.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Galls.*	*°F.*	
1	Town well	Bristol	22	Driven	1¼	22	−10	Gravel and sand.				
2	Elkhart Water Co.	Elkhart	34	Dug	[a] 40	30	− 6	Gravel				1,2,8
3	Island Park	do	85	Drilled	2	80	+ 3	do		10		3
4	McNaughtons Park	do	80	do	2	80	+ 3	do				
5	Chicago Telephone Supply Co.	do	25	Driven	1¼	25	− 6	do				
6	R. L. Evans	do	124	do	2	65	+ 0	do	122			
7	M. W. Huston	do	80	do	2	65	+ 2	do				
8	Sidway Mercantile Co.	do	20	do	2	20	−12	do				
9	City waterworks	Goshen	36	Dug	[a] 40	20	− 2	do				15
10	Hawks Furniture Co.	do	80	Driven	1¼	80		do				
11	Goshen Manufacturing Co.	do	25	do	1¼	20	−18	do				16
12	Banta Furniture Co.	do	25	do	1¼	20	−13	do				17
13	L. J. Pritchard	Jamestown	26	do	1¼	26	−12	do				
14	Town well	Middleburg	24	do	1¼	24		do				
15	do	Millersburg	28	do	1¼	28	−18	do				18
16	Public supply	Nappanee	160	Drilled	6	100	−40	do				19
17	Town well	New Paris	15	Driven	1¼	15	− 8	do				20
18	Henry Wagner	Wakarusa	28	do	1¼	28	+ 2	do		2	51	21
19	Irene Smeltzer	do	30	do	1¼	30	+ 7	do		5	51	
20	Leroy Mullenauer	do	60	do	1¼	60	+ 2	do		4	51	

[a] Feet.

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Mineral analyses of waters in Elkhart County.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Parts per million.															No. in record of wells.
							Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	
1	Public supply	Elkhart	Open wells, 34 ft			Gravel	15	2.5		68	4.3	3.9		99		23	6.1				234	2
2	Do	do	do	Chase Palmer	Oct., 1907	do	10	0.5		46	21	6.3		12	182	9.2	2.0	0.6			221	2
3	Island Park	do	Well, 85 ft. by 2 in	H. E. Barnard	1907	do		.10		29	11				231	12	52	.40	.000	2	254	3
4		do	Elkhart River[a]	Lake Shore and Michigan Southern R. R.	1903			2.0		67	19	4.7		129		33	3.2	.00				
5		do	do.[b]	do	1903			2.7		71	18	8.8		132		41	3.9	.00				
6		do	St. Joseph River[c]	do	1903–1907			1.5		59	18	3.5		121		22	2.8	1.5				
7		do	do.[d]	do	May, 1903			1.5		57	17	2.0		116		17	3.0					
8	Public supply	do	Wells, 34 ft	do	Feb., 1903	Gravel		1.2		53	20	5.5		125		15	3.8	.00				2
9	A Zimmerman	do	Well, 80 ft. by 4 in	do	June, 1903	do		1.5		61	18	5.8		132		17	1.9					
10	(Field House addition.)	do	Well, 65 ft. by 2½ in	do	do	do		.98		97	23	16.00		157		73	25					
11	Island Park	do	Well, 60 ft. by 2½ in	do	do	do		1.2		66	19	4.2		141		12	4.6					
12	(Johnson's addition.)	do	Well, 75 ft. by 2½ in	do	do	do		1.5		73	20	10.00		148		26	7.9					
13	City supply	Goshen	Rock Run	do	Aug., 1903			2.9		55	19	2.9		118		16	4.5	4.0				
14	Do	do	do	do	Dec., 1904					67	22	2.5		141		18	3.8	4.5				
15	Do	do	Open wells, 24 and 40 ft.	Chase Palmer	Oct., 1907	Gravel	18	0.2		50	21	8.2		11	198	15	1.8	Tr.			240	9
16	Goshen Manufacturing Co.	do	Well, 25 ft. by 1¼ in	H. E. Barnard	1907	do		.01		76	19			0.0	239	66	11	2.0	.001	2	370	11
17	Banta Furniture Co.	do	Well, 23 ft. by 1¼ in	do	1907	do		.01			28			.0	334	564		3.5	.001	4		12
18	Public well	Millersburg	Well, 28 ft. by 1¼ in	do	1907	do		.00		93	38			.0	306	46	20	8.0	.00	9	484	15
19	Public supply	Nappanee	Wells, 100 to 160 ft.[e]	do	1907	do		1.0		76	36				365	46	28	.30	.00	9	380	16
20	Public well	Farman Bros. store, New Paris.	Well, 15 ft. by 1¼ in	do	1907	do		.10		89	30			.0	263	101	260	6.0	.00	4	412	17
21	Henry Wagner	Wakarusa	Well, 28 ft. by 1¼ in	do	1907	do		.10		74	27			.0	291	107	12	.10	.00	2	362	18

[a] Average of three analyses. [b] Normal stage. [c] Average of five analyses. [d] Low stage. [e] Water at 100 feet.

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FULTON COUNTY.

SURFACE FEATURES AND DRAINAGE.

Fulton County is in the western tier of counties of this area and is bordered on the north by Marshall and Kosciusko counties and on the south by Cass and Miami. It is irregular in outline and is notched on its east edge by the corners of Kosciusko and Miami counties. It has an area of 382 square miles, and had, in 1900, a population of 17,453, or an average of 45 inhabitants to the square mile. The county seat is Rochester.

The surface is of mild relief and a large part of it lies between 750 and 800 feet above sea level. At the southwest corner and in that part of the Tippecanoe Valley which lies northwest of Rochester the land surface falls below the 750-foot level, but in the narrow east end of the county it reaches a height of 900 feet. (See Pl. I.) Almost all of the county may be classed as uplands. A great interlobate moraine (Pl. I) crosses the southeast and east edges of this area, and the Tippecanoe River valley forms the south border of the great Maxinkuckee moraine. A narrow belt of low moraine also extends across the county from north to south near its western edge, and there is still another patch of moraine southeast of Rochester, in which Lake Manitau has its basin. In all of the morainic areas the surface is rolling and irregular. On either side of Tippecanoe River, and extending from this valley through the center of the county southward as far as Rochester, is a plain formed of alluvial sands and gravels which have locally been blown to form low dune ridges. That part of the surface which is not occupied by morainal or alluvial material consists of gently undulating till plains. (See Pl. I.)

Fulton County contains about two dozen natural lakes and ponds. The largest of these, Manitau Lake, near Rochester, has an area of little more than a square mile, while most of them only occupy a few acres of ground. All are in the moraine-covered portions of the county and lie in depressions in the irregular surface of the moraines.

Tippecanoe River, in the north part of the county, is its only important stream. Its valley makes a great crescentic curve around the south edge of the Maxinkuckee moraine, and the stream bed is not more than 30 or 40 feet below the alluvial plain to the south. With the exception of a small area in its extreme southeast corner, the entire county drains into the Tippecanoe. The principal tributaries are Grass, Mill, Mud, and Chippewanuck creeks from the south and Eddy Creek from the north.

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GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

As stated above, the alluvial deposits of Fulton County are of considerable extent in the Tippecanoe Valley and cover a part of the plain to the south of it. The alluvium consists of gravels and clayey sand and was here deposited beyond the edge of the retreating glacier by the streams which flowed from it. The surface is flat and has suffered little from stream erosion. West of Rochester the winds have blown the alluvial sands into low ridges or dunes.

Throughout the area of alluvial deposits (Pl. I) the ground-water supply is abundant and easily obtained. In the valley of the Tippecanoe and in the prairie west of Rochester only driven wells are used. These wells are obtained easily by driving a 1¼-inch pipe with a perforated point 20 or 30 feet into the sand or gravel. Some of the wells become clogged with fine sand, but if gravel beds can be reached, this trouble is avoided.

Over most of the morainal areas, shown in Plate I, the morainal drift is only moderately thick and the relief is mild. The most vigorous moraine of the county lies north of Tippecanoe River in the neighborhood of Tiosa and Richland Center. In the high moraine in northern Fulton County the wells are almost all driven or drilled. The shallowest are about 30 feet deep, but occasionally it has been necessary to sink wells 150 or even 200 feet. The best supplies of water are always found in gravel or coarse sand beds, which in the areas of thin morainal drift can commonly be reached at depths less than 100 feet.

The occurrence of the till at the surface is shown in Plate I. The surface is in some parts a flat featureless plain, but more generally it consists of gentle, wavelike undulations with the crests only a few feet above the troughs. In those areas where the till occurs at the surface it extends downward to bed rock, which is everywhere more than 150 feet below the surface, and it therefore follows that all wells of ordinary depth must get their water in the till. For this reason dug wells, which obtain the water by slow seepage from the clayey till, are most common.

CONSOLIDATED MATERIALS.

In only two towns in the county were records obtained of wells which have penetrated to bed rock. At Rochester rock was found at 150 feet and at Kewanna 170 feet below the surface. Deep borings in the surrounding country show the surface deposits to reach similar thicknesses. With such meager data it has been impossible to ascertain closely the distribution of the various rock formations beneath the glacial deposits. Furthermore, up to the present time

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it has nowhere been necessary in this county to go to rock for water supplies and no wells now receive their supplies from the rock. If occasion should arise in the future for seeking additional water-bearing beds, it is likely that water will be found in the Silurian ("Niagara") limestone which here underlies the surface deposits. The Silurian waters are discussed on pages 42–43.

ARTESIAN AREAS.

At Talma, which lies on a gravel terrace along Tippecanoe River (Pl. IV, No. 23), there are three flowing wells and others in which the water rises nearly to the surface. These wells are all about 30 feet deep, the water coming from a gravel bed below hardpan. One bored well, 12 inches in diameter (No. 14, p. 115), for many years yielded 36 barrels of water per hour, but its flow has now diminished somewhat. In this area flows can be expected only from wells in the lowlands near the river.

Several flowing wells are reported to occur in an area 2 miles east of Lake Manitau. (Pl. IV, No. 24.) The surface is here covered by a moraine of low relief, and the artesian waters are doubtless obtained from local gravel beds in the moraine. No information could be obtained in regard to the character or depth of the wells.

In the valley of Grass Creek, 2 miles southwest of the town of the same name, there is a fine flowing well (Pl. IV, No. 25) 2 inches in diameter and 35 feet deep. The water, from a gravel bed, rises 4 feet above the surface, and the flow is about 20 gallons per minute. The yield diminishes somewhat in the dry months of the summer, showing that the head of the water is local and that the supply furnished by the rainfall on the surface is at no great distance from the well. Other flowing wells could doubtless be obtained in the neighboring lowlands.

Flowing wells have been obtained in the lower portions of the city of Rochester. (Pl. IV, No. 26.) In 1887 a deep well was bored for gas and encountered artesian waters which for a while had sufficient pressure to rise in the pipe 8 feet above the surface. It is not known certainly from what depth this flow came. In 1907 another flowing well was obtained. (No. 12, p. 115.) This well was driven 72 feet into a gravel bed, and flows about 2 gallons per minute 8 feet above the surface of the ground. Probably other flows could be obtained from this same gravel at points near by.

CITY AND VILLAGE SUPPLIES.

Rochester.—Rochester, the county seat of Fulton County, lies on the edge of an alluvial plain which extends westward from the city for several miles and north to Tippecanoe River, while southeast of the city the surface is covered with moraine deposits. The city

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installed a waterworks system in 1893, the water being drawn from an old mill race fed by Manitau Lake, a shallow lake lying in the low moraine a mile southeast of the city. The lake itself is surrounded by timber and open land and should afford a good city supply, for although there are a number of houses along its shores there should be little difficulty in preventing pollution of the lake water from these. The water is soft, and though not well suited for drinking it is otherwise of good quality. Unfortunately the water is not drawn directly from the lake but flows for about three-fourths of a mile through an old mill race and is drawn from this near the pumping works. Between the lake and the intake pipe the race is open, and there is every opportunity for it to become polluted. Privies and barns line the banks in town, and the drainage from these and from kitchen slops and swill barrels can enter this open ditch, which itself is foul with weeds and débris. A pipe line directly to the lake from the pumping works would greatly increase the safety of this source of supply.

The city water is pumped from the mill race to a standpipe, holding 105,000 gallons, from which it is distributed by direct pressure to 10 miles of mains. About one-fourth of the people are supplied by the city and use an average of 400,000 gallons per day. Each family has a private well for drinking water, and the city water is only used for other domestic purposes, for irrigation, and for industrial purposes.

At Rochester wells may be sunk cheaply and with great probability of success. The underlying materials are alluvial gravel and fine sands and silts. Driven wells, from 15 to 80 feet deep, are numerous and almost without exception find never-failing supplies of good water. Some few wells have gone deeper than 80 feet, but the most abundant waters are found at moderate depths. Analyses of gravel waters from this city appear on page 116 of this report. As shown by the records of many shallower wells and of one deep boring at Rochester, the succession of beds is about as follows:

Generalized section of the strata at Rochester.[a]

	Feet.
Alluvium	35
Glacial till	115
Subcarboniferous and Devonian shale	395
Devonian and Silurian limestones	525
Hudson River and Utica shales	391
Trenton.	

Kewanna.—The town of Kewanna installed public waterworks in 1907, the supply being drawn from a 10-inch drilled well, 150 feet in depth, which penetrated a gravel bed in the till and yielded a large volume of water when tested. A pneumatic pressure system operated

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 257.

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by a gasoline engine is used. The water is pumped into two tanks 10 feet in diameter and 30 feet long, partly filled with air, and from the tanks the water is forced by the air pressure through the mains. At the time the town was visited (October 25, 1907) about 1¾ miles of mains had been laid.

Before the public water system was installed the water supply of Kewanna was obtained from privately owned dug or driven wells. The dug wells range from 20 to 90 feet in depth; the average depth of the driven wells is about 90 feet, at which depth a gravel bed is generally encountered. The deeper waters are cool and pure and form an excellent source of supply.

Akron.—Akron is situated at the east end of the county near the line where the till plain to the west gives place to the more irregular topography of the moraine. There are still a few dug wells in use in this town, though driven wells, which range in depth from 40 to 60 feet, are much more common. A bed of gravel is in most wells encountered between these depths, and the water from it rises within 20 feet of the surface. There is no public water supply, as the private wells furnish an abundance of pure water.

Tiosa.—Tiosa is in the north-central portion of the county, in the hilly area of the Maxinkuckee moraine. Driven wells are used here almost altogether, and gravel, bearing abundant water, is commonly found at about 50 feet below the surface. This is known locally as the "second gravel," and the water, though hard, is pure and wholesome.

Fulton.—The town of Fulton lies in the south-central part of the county, 9 miles south of Rochester. Its water supply is drawn altogether from driven wells, all 30 feet or less in depth. They pass through a loose sandy clay into gravel at 10 to 15 feet below the surface, and most of them are driven but a short distance into this gravel. There is no sewage system in Fulton, and each dwelling has a dug privy vault. Much of the liquid matter from the outhouses and from kitchen refuse and barns sinks into the ground and becomes part of the underground water supply from which the well water is drawn. The water from these wells must, therefore, be dangerous for domestic use. Deeper wells would probably find gravel below clays, which would protect the water from pollution and yield a safe water supply.

Other communities.—In the following table is a list of other communities in Fulton County, with particulars regarding their water supply:

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Other village supplies in Fulton County.

Town.	Population (1900).	Source.	Depth of wells.			Head below surface.	Character of water beds.
			Least.	Greatest.	Common.		
			Feet.	*Feet.*	*Feet.*	*Feet.*	
Athens	125	Wells, driven	35	40	35	10	Gravel.
Blue Grass	142	do	25	35	33	8	Do.
Bruce Lake	50	do	23	114	90	25	Do.
Delong	75	do	25	55	40	15	Do.
Olsko	150	Wells, driven and dug.	12	43	35	15	Do.
Fletcher	20	Wells, driven	60	100	75	.....	Gravel and sand.
Germany	17	do	10	30	20	6	Do.
Grass Creek	136	do	30	110	30, 100	.....	Gravel.
Greenoak	32	do	40	60	50	.....	Gravel and sand.
Leiters Ford	145	do	35	60	45	18	Gravel.
Richland Center	50	Wells, drilled	90	195	160	.....	Gravel and sand.
Showley	10	Wells, driven	50	75	65	.....	Gravel.
Talma	125	Wells, driven and bored.	12	40	36	0-8	Do.
Wagoner	105	Wells, driven, bored, and dug.	15	170	100	30	Gravel or sand.

TYPICAL WELLS AND ANALYSES.

In the two following tables are given the records of typical wells in Fulton County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in Fulton County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute	Analysis No.
			Ft.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Galls.*	
1	E. A. Spaugy	Akron	13	Dug	.....	13	.....	Gravel	.....	.....	2
2	J. Q. Howell	Delong	51	Driven	1¼	50	−15	do	.....	.....	3
3	Town well	Fulton	13	do	1¼	12	− 8	do	.....	.....	5
4	James Costello	2 miles W. of Grass Creek.	35	do	1¼	35	+ 4	do	.....	20	.....
5	Public supply	Kewanna	150	Drilled	10	.....	−30	do	.....	.....	.....
6	Town well	do	83	Driven	1¼	80	−20	do	.....	.....	6
7	David Frye	Richland Center	160	Drilled	.....	160	.....	do	.....	.....	7
8	Court-house	Rochester	580	do	.....	580	.....	Limestone	155	.....	13
9	Public well	Main and Seventh streets, Rochester.	48	Driven	.....	48	.....	Gravel	.....	.....	14
10	do	Main and Fifth streets, Rochester.	47	do	.....	47	.....	do	.....	.....	12
11	F. C. Morse	Rochester	89	do	.....	.....	.....	do	.....	.....	.....
12	Charles Langdorf	do	72	do	1¼	72	+ 8	do	.....	2	11
13	Mrs. R. Henry	Talma	36	do	1¼	36	+	do	.....	20	15
14	Eschuyler Tipton	do	36	Bored	12	36	+	do	.....	.....	.....
15	Samuel Kepler	do	36	Driven	1¼	36	+	do	.....	.....	.....
16	E. S. Bair	1 mile SE. of Tiosa	160	Drilled	.....	160	.....	do	.....	.....	.....
17	H. Kestner	Tiosa	33	Driven	1½	33	.....	do	.....	.....	16

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Mineral analyses of waters in Fulton County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	C. F. Hoover	Akron	Well, 57 ft. by 2 in.	H. E. Barnard.	Sept., 1907			2.0		76	21			0.0	228	13	10	0.2	.001	4	272	
2	E. A. Spaugy	do	Open well, 13 ft.	do	do	Gravel		.3		87	19			.0	25	58	30	16	.001	4	564	1
3	J. Q. Howell	Delong	Driven well, 51 ft. by 1¼ in.	do	1907	do		2.4		73	24			.0	289	24	10	.010	.001	4	302	2
4	Erie Railroad	Disko	Well, 12 ft.	W. S. Landon.	Mar., 1905			1.9		99	29	16		191		66	9.1					
5	Public well	Fulton	Driven well, 13 ft. by 1¼ in.	H. E. Barnard.	1907	Gravel		.01		144	39			.0	352	206	58	.010	.001	2	782	3
6	do	First National Bank, Kewanna.	Driven well, 83 ft. by 1¼ in.	do	1907	do		.3		64	28			.0	261	84	4	.010	.001	2	388	6
7	David Frye	Richland Center.	Drilled well, 160 ft. by 2 in.	do	Sept., 1907	do		.04		84	34			24	241	15	9	.05	.00	4	384	7
8	Public supply	Rochester	Manitau Lake	W. B. Landon.	Apr., 1905		0.5	1.0		57	17	2.3			111	22	9.2					
9	do	do	do	Lake Shore and Michigan Southern Railroad.	Sept., 1904			.36		27	14	2.9		67		16	1.3					
10	do	do	Mill race at waterworks intake.	H. E. Barnard.	Sept., 1907			.3		24	18			.0	121	27	2.0	.20	.001	42	218	
11	Charles Langdorf	do	Driven well, 72 ft. by 1¼ in.	do	do	Gravel		2.8		87	20			.0	253	20	4.0	1.00	.020	4	310	12
12	Public well	Fifth and Main streets, Rochester.	Driven well, 47 ft.	do	do	do		.01		81	22			.0	204	9.9	8.0	.000	.00	13	364	10
13	Court-house well	Rochester	Drilled well, 580 ft.	W. Van Winkle	do	Limestone	18	.6		72	28	21		.0	382	8.2	3.0	.44			326	
14	Public well	Seventh and Main streets, Rochester.	Driven well, 48 ft.	do	do	Gravel	17	.9		84	24	5.6		.0	369	13	2.0	.5			333	9
15	Mrs. R. Henry	Talma	Driven well, 36 ft. by 1¼ in.	H. E. Barnard.	Nov., 1907	do		.2		82	25			.0	295	9.9	2.0	.20	.00	4	354	13
16	H. Kestner	Tiosa	Driven well, 33 ft. by 1¼ in.	do	Aug., 1907	do		.04		126	35			.0	284	78	41	.10	.00	4	590	17

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GRANT COUNTY.

SURFACE FEATURES AND DRAINAGE.

Grant County lies in the east-central portion of the area included in this report and extends 7 miles farther east than any other county. It is rectangular and has an area of 416 square miles. The population as shown by the census of 1900 was 54,693, or 131 persons to the square mile. This large population is due both to the excellence of the farming lands and to the boom which the eastern half of the county has experienced from the development of the natural gas and oil fields.

With the exception of the Mississinewa River valley the whole of Grant County consists of uplands. West of this river the surface is a plain of very slight relief. Its character is somewhat undulating, but there are no pronounced prominences, and the valleys are all shallow. The plain is nowhere 100 feet above the river. There are also plains east of the river in the southeast corner of the county and in the northeast corner (Pl. I). East of Mississinewa River, and roughly parallel with it, is a well-defined moraine ridge which lies on top of the till beds. It is nowhere more than 50 feet thick, but its ridgelike form and its irregular surface distinguishes it from the surrounding plains of till.

In the uplands the form of the surface has no relation to that of the underlying rock. All the inequalities of the rock surface have been covered by a filling of glacial deposits, and the rock outcrops at only a few points in the bottom of the Mississinewa Valley.

The largest and only important stream of the county is Mississinewa River, which crosses the county from southeast to northwest to join the Wabash near Peru. Its valley, though shallow, is well defined. At Marion the stream flows about 50 feet below the level of the surrounding uplands, and at the north edge of the county the valley is somewhat less than 75 feet deep. The ledges of limestone which outcrop below Marion have retarded the deepening of the valley above them. The Mississinewa basin is rather narrow in Grant County. Pipe and Wild Cat creeks drain the western part of the county and tributaries of Salamonie River, the northeast portion,

There are no lakes of importance in Grant County, for although lakes are common in moraines in general the moraine here is of low relief and is so close to the Mississinewa Valley that any lakes which may have existed have been long since drained by the natural deepening of their outlets.

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GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Much information in regard to the thickness of the surface deposits in the county has been obtained from the numerous borings for oil and gas. The rock surface, before it was covered by glacial ice, was crossed by streams which had cut valleys over 300 feet into the rock, but the glacial deposits filled these up and leveled the county over. The old preglacial valleys have had no influence upon the courses of the present streams, but in places cause a great thickening in the unconsolidated surface materials above them.

The alluvial deposits of this county all occur along the bottoms of the larger valleys, more especially that of Mississinewa River, where they have a width of one-fourth to one-half mile. The thickness of the alluvium varies in different portions of the valley. Below Marion the valley has been lowered to the "Niagara" limestone, which outcrops along the stream bed, and here the alluvium, where present at all, forms only a thin veneer over the rock in the river flat. South of Marion the rock surface dips downward and the alluvium is thicker. The smaller stream valleys all have alluvial deposits varying in amount with the size and development of the valley.

An abundant supply of excellent water can be procured almost anywhere in the alluvium, and it is generally not necessary to sink deep wells in order to reach the waters. In the first bottom the waters are found slightly above the level of the stream, but in the higher gravel terraces the water table is farther from the surface.

Grant County contains a single moraine belt which lies east of and parallel with Mississinewa River (Pl. I). It is 5 or 6 miles wide and continuous, though nowhere of great prominence. The crest of the moraine stands about 50 feet above the adjoining till plains. Throughout the morainal belt most of the wells are drilled, and extend to gravel beds at 70 to 100 feet below the surface. As the moraine is for the most part not more than 50 feet thick it is evident that the supply from these wells is from the till below the moraine. Locally driven wells encounter gravel at 50 feet or less below the surface, and some dug wells in the morainal clay obtain small amounts of water.

Over three-quarters of Grant County is covered by a mantle of till which conceals the rock and varies in thickness in different parts of the county up to 400 feet. This variation is due almost altogether to the irregularities of the underlying rock surface, for the till itself forms a remarkably flat, featureless upland. One of the most prominent features of the rock surface, although there is no trace of its existence in the present surface topography, is a great canyon-like

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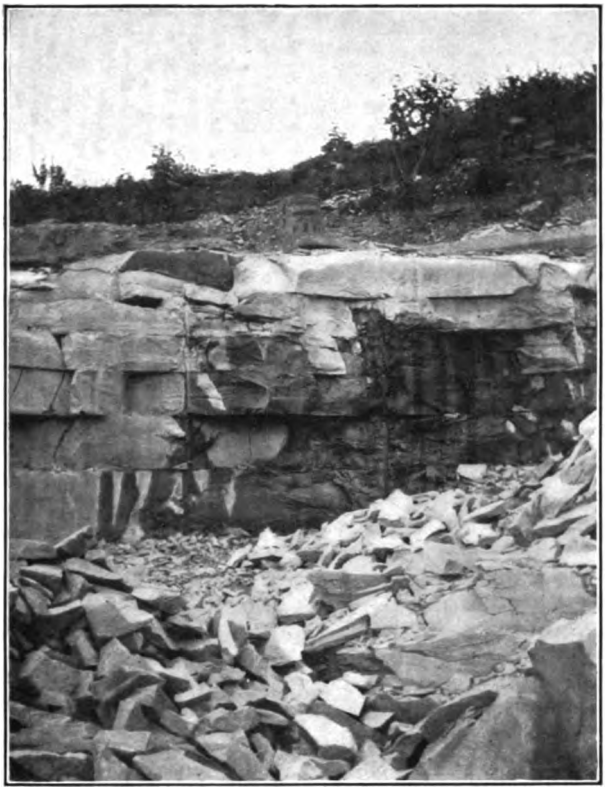
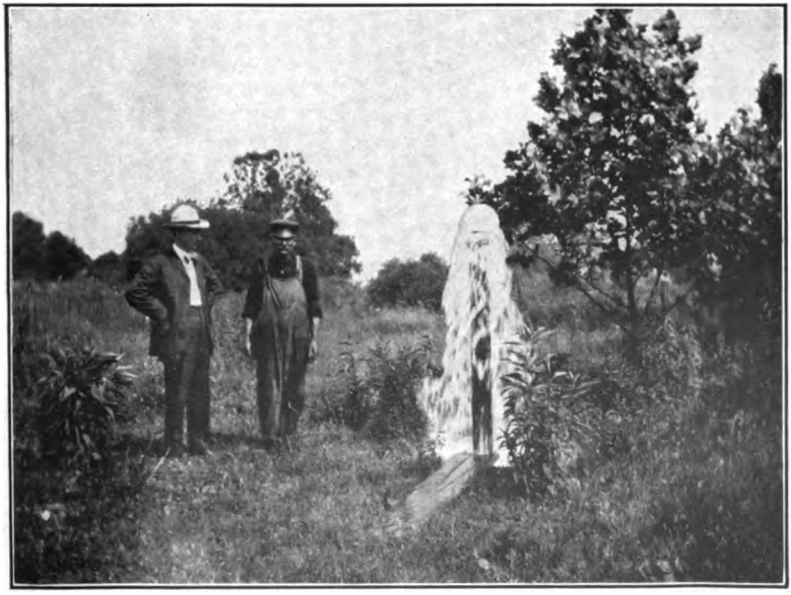


A. WATER OOZING FROM BEDDING PLANES OF LIMESTONE.



B. FLOWING WELL AT DANVILLE WATERWORKS.

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valley, 200 to 300 feet deep, which crosses the northeast corner of the county. Mr. J. A. Bownocker[a] has traced this valley from Ohio River up the valley of the Little Miami to New Carlisle, Ohio, and thence west and northwest into Grant County. Additional well records show it to continue northwest beyond La Fountaine, and it doubtless extends still farther northwest. One well in Miami County, about 4 miles north of Peru, is reported to have penetrated over 300 feet of drift without entering rock, and the suggestion is made that the well may be in a continuation of this same deep preglacial valley (Pl. II). In the Mississinewa Valley below Marion the rock has been exposed by stream cutting, and in the southwest corner of the county, north of Rigdon, it rises within 6 feet of the surface. Thus the thickness of the till is seen to vary within wide limits in different parts of the county. Plate II shows the depth to rock throughout the area.

The till is in some places very clayey and lacking in beds of gravel and sand. When this condition prevails the supply of water is small and has to be obtained from dug wells, most of which yield only enough water for domestic purposes. Where the till is thick deep wells almost everywhere encounter good supplies in gravel, and in that part of the county where the till is thin wells are drilled into the rock.

CONSOLIDATED MATERIALS.

The first rock formation which wells enter below the surface deposits is the "Niagara" limestone. This is true of all deep wells except a few sunk in the deep preglacial valley in the northeast part of the county, where the preglacial stream had cut its canyon through the limestone to the underlying shale. The depth to the "Niagara" varies greatly, as shown in Plate II. The available water in the "Niagara" limestone all occurs in the joints and bedding planes, which have in many places been dissolved out by the circulating waters to form continuous channels. Plate VI, *A*, illustrates the manner in which the water follows the bedding planes. In the deeper valleys and in those areas where this formation comes close to the surface, the "Niagara" has become an important source of water supply. Wells drilled into the limestone are sure to encounter openings from which water can be obtained. It is because of this abundance of rock water that all gas and oil wells are cased below this formation to keep its waters from mingling with the oil and gas from below. In the deeper valleys the waters in many wells flow a few feet above the surface, and in the higher lands they rise to about the same level but will not flow.

[a] Special Paper No. 3, Ohio State Acad. Sci., 1900.

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ARTESIAN AREAS.

Artesian area 27 (Pl. IV) includes all of the lowlands along the valley of the Mississinewa and extends somewhat up the valleys of its larger tributaries. Most of the flowing waters are from the "Niagara" limestone, but some are from gravel. By far the greater number of the wells were originally drilled for oil or gas. In drilling such wells a pipe, 8 or 10 inches in diameter, is driven down to the rock. When the boring reaches the bottom of the "Niagara" its size is commonly reduced to 6 inches, and a pipe, the casing, is put down to the bottom of the rock to keep the rock waters out of the well. If oil or gas is found, the casing is left in and the flowing waters emerge between the drive pipe and the casing. If the well is unsuccessful or becomes exhausted, the pipes are generally "pulled." A state law requires that all "pulled" wells be plugged at the base of the limestone to prevent the mingling of waters from different depths. When both casing and drive pipe are pulled the surface deposits cave in and fill the hole. Many flowing wells in this area have been destroyed in this way, as the pipes are the property of the company which drilled the well. In some places the owner of the land upon which the well is located buys the drive pipe from the company and keeps the well for its water supply. Most of the present flows have been retained in this way.

In some localities wells supplied by water from the "Niagara" limestone are in "sympathy"—that is, if one well of a group is drawn upon heavily it may affect the head of other wells for some distance around. This underground connection is in many places very marked. A striking illustration of this phenomenon is shown in the "sympathy" between the flowing well at Matter Park and the wells of the Marion Paper Company, one-half mile southeast. For six days each week the wells of the paper company are pumped heavily, and during this time the Matter Park well ceases to flow, and the water is raised by a small pitcher pump (Pl. VII, *B*). On Sunday the paper mill is idle, and the park well yields a strong flow (Pl. VII, *A*).

In addition to the flowing waters from the "Niagara," many good flows have been obtained in Marion from gravel beds in the till. The wells range from 40 to 150 feet in depth and the artesian waters are confined in gravel beds below pebbly till. The flows are small, only one well having been observed which flowed more than 2 gallons per minute. The temperature of the gravel waters is 52° F.

Many deep borings for gas in the valley of Pipe Creek above and below Mier have obtained flows of artesian water from the "Niagara" limestone. (Pl. IV, No. 28.) This valley has here about the same elevation as the valley of the Mississinewa between Marion and Gas City. The head of the flowing waters comes from the higher portions

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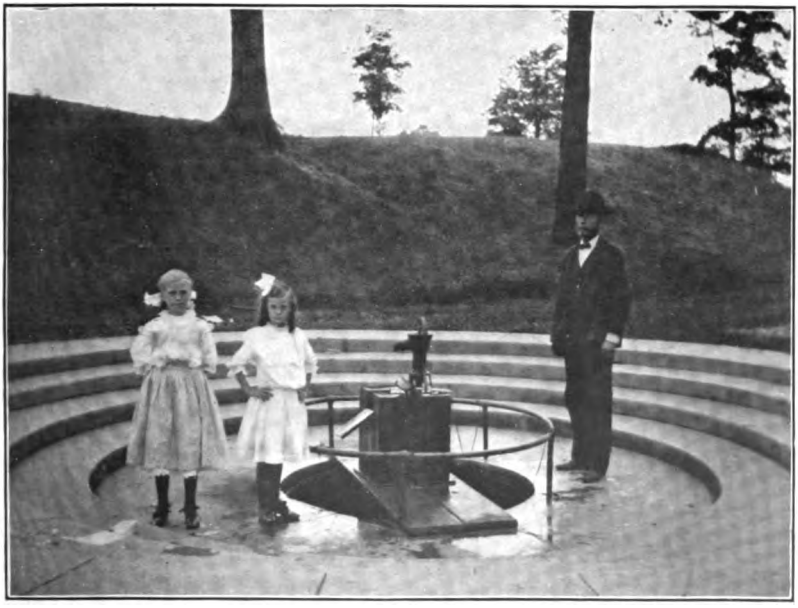
A. FLOWING WELL AT MATTER PARK, NEAR MARION, IND.



B. WELL AT MATTER PARK WHEN WELLS AT PAPER MILL, ONE-HALF MILE AWAY, ARE BEING PUMPED.

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of the limestone to the south, and the impervious till covering prevents the natural escape of the waters. Most of the flowing wells of Pipe Creek valley have been destroyed by the pulling of the pipes.

CITY AND VILLAGE SUPPLIES.

Marion.—The public supply of Marion is drawn from drilled wells of various depths. There are 17 wells, of which 14 are now in use, and all are said to flow when not pumped. One well was estimated to flow 50,000 gallons per day when it was drilled, but the head gradually became lower as more wells were sunk. A few wells get water at a depth of 68 feet from a gravel bed below till, but most of the water is obtained from the "Niagara" limestone, which is encountered at 80 to 150 feet below the surface. The water system is owned and operated by the city, and the water is pumped from the wells by an air lift into three reservoirs of 200,000, 750,000, and 2,000,000 gallons capacity. From the reservoirs it is pumped by steam into the mains. About 2,500,000 gallons per day is needed to supply 75 per cent of the population of the city. Analyses of this water are given on page 126.

The conditions for obtaining wells in Marion are so diverse that no general statement can be made to cover them all. The rock is exposed in parts of the river bed, and lies at various depths elsewhere, up to 200 feet in the higher parts of town, the surface deposits consisting of blue till, sand, and gravel. Where the rock comes close to the surface most of the wells are drilled and secure their supply from limestone. If the surface deposits are deep, dug or driven wells are more common. The character of the surface deposits and the depth to rock in different parts of the city are given by Bowman[a] in a paper issued by this Survey. Most wells sunk into either the surface deposits or the rock are successful, and only a few wells out of the many hundreds which have been drilled into the limestone have failed to procure abundant water. The following is a record of a successful gas well in this city:[b]

Log of gas well at Marion.

	Feet.
Drift	70
Niagara limestone	280
Hudson River and Utica	528
Trenton limestone	22
	900

The ground waters in the vicinity of Marion have been considerably polluted by the salty and oily waters from oil wells. The conditions and suggestions for a remedy are set forth in Bowman's paper.

[a] Bowman, Isaiah, and Sackett, R. L., The disposal of strawboard and oil-well wastes: Water-Supply Paper U. S. Geol. Survey No. 113, 1905, pp. 36–42.

[b] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 251.

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Gas City.—The Gas City waterworks, built in 1898, are owned by the city, and the water is drawn from three wells located on the Mississinewa River flat, at the west edge of town. The deepest well is an old gas well, which has been plugged at a depth of 325 feet and draws its supply from the "Niagara" limestone. Another well also secures limestone water at 200 feet below the surface, while the third penetrated 28 feet into the alluvial gravel. The water from all three wells is raised by air pressure to a reservoir, from which it is forced by steam pumps directly into the mains. About 500 taps are in use and 60 per cent of the people of the city are supplied by this system.

The sanitary condition of the water from all three wells is good, as they are located at some distance from the thickly settled district. There are only three houses within one-fourth mile of the wells.

Many privately owned drilled and dug wells are in use in Gas City, and over one-third of the people rely on these wells for their water supply. The wells range from 35 to 300 feet in depth, and though some find sufficient water in the surface deposits, others go to rock, which lies from 150 to 180 feet below the surface. The town is situated on a till plain and all the well water is hard. There are no springs or flowing wells.

Fairmount.—The Fairmount public waterworks were installed in 1894 and are owned and operated by the city. The supply is drawn from six wells drilled into the limestone which here lies 20 to 40 feet below the surface, and waters under artesian pressure rise to within a few feet of the level of the ground. No reservoir or standpipe is used, and the water is pumped directly from the wells into the mains. About 400 taps are supplied by 4 miles of 10, 8, 6, and 4 inch mains, and an average of 300,000 gallons of water per day is used to supply 65 per cent of the people of the town. The water furnished is good and is the best available. Analysis (No. 2, p. 127) shows it to be rather high in chlorine and sulphates, possibly from the salt waters from neighboring oil or gas borings, but these minerals do not occur in objectionable amounts.

Most of the privately owned wells in Fairmount are drilled, but a few dug wells are still in use. The drilled wells range from 20 to 90 feet in depth, though the greater number are about 40 feet deep. The best supplies of water are from rock, which is reached at depths of 20 to 40 feet.

Jonesboro.—The Jonesboro public supply, owned by Trowbridge & Niver, is drawn from a dug well, 25 feet deep and 15 feet in diameter, sunk into the gravels in the valley of Back Creek. Direct pressure is used and an average of about 225,000 gallons of water a day is needed to supply 150 services.

The well is at the base of a steep slope and is subject to surface pollution. At times the water is noticeably salty, doubtless from the

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salt waters from oil wells farther up the creek. At times, too, a reddish deposit collects in the mains in quantities sufficient to color the water. This could be remedied by frequent and thorough flushings of the mains.

A much safer supply of water could here be obtained from the limestone by drilled wells. All danger from surface contamination would be avoided and the water, though harder, would be better for domestic purposes. An analysis of the city water is given on page 127.

In Jonesboro there are many private wells which range from 15 to 60, but are commonly 40 feet in depth. They are dug or drilled and are supplied by waters from the gravel beds in the till. The rock here lies from 130 to 160 feet below the surface and therefore is too deep to be readily accessible for ordinary wells.

Upland.—In 1892 the Upland Water Works Company, a private corporation, installed a public supply for Upland, the water being drawn from a single well, drilled through 192 feet of till into limestone. There are 3,600 feet of city mains, 4, 3, and 2 inches in diameter, into which the water is forced by direct pressure from steam pumps. One hundred and forty taps supply water to about 60 per cent of the inhabitants, and about 40,000 gallons of water are used per day. The city water has a slight taste of oil, doubtless due to the imperfect plugging of abandoned oil or gas wells in the vicinity. Although this oily taste is somewhat objectionable, the water is not known to be unhealthful.

A number of dug or driven wells are still in use in Upland. The dug wells are 15 to 25 feet deep, and all fail in dry seasons, but the driven wells are more successful. A bed of gravel encountered at 110 feet supplies unfailing waters.

Vanburen.—The public waterworks of Vanburen are owned by E. S. Sutton, and a single well, drilled in 1903, furnishes the supply. This well, 8 inches in diameter, was sunk 140 feet through surface deposits and 35 feet into limestone before water was struck. At 195 feet the well was shot with 12 quarts of nitroglycerine to fracture the rock and increase the supply of water. The well now furnishes enough water for the present consumers, but is pumped to about its full capacity. The water is lifted by a steam pump to a standpipe 65 feet high, whose capacity is 400 barrels, and from this it is distributed by gravity. There are 1½ miles of mains and 130 consumers, who use about 2,000 barrels of water a day. The water is hard and has a slight taste of iron, but is wholesome. An analysis of it is No. 23 (p. 128).

Vanburen is situated on a gently undulating till plain. Most of the private wells are driven from 60 to 80 feet deep, and procure plenty of water in gravel. There are some dug wells, but many of these fail in times of drouth.

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National Military Home.—The National Military Home at Marion is supplied with water from 14 drilled wells, of which 12 are 87 feet deep and reach a water-bearing bed of gravel. Two other wells in limestone, of which one is 340 and the other 500 feet deep, are not used at present, as the gravel wells furnish sufficient water. The water is pumped to a standpipe 125 feet high, which holds 240,000 gallons, and the pressure is furnished by gravity from the standpipe. There are 3 miles of mains and 1,900 people are supplied, the average amount pumped daily being 500,000 gallons. The water is good, though it tastes strongly of hydrogen sulphide and iron.

Matthews.—Matthews has no public supply. Many privately owned drilled, driven, or dug wells are in use. The dug wells, which are 15 to 30 feet deep, are apt to fail in dry seasons and many have been abandoned. The driven wells are commonly about 60 feet deep and furnish good supplies of gravel water. An analysis of water from a gravel well in Matthews is No. 19 (p. 128). Most of the wells are drilled into the rock, which is here entered at 85 to 113 feet below the surface, although along the river bottoms some borings have reached rock within 35 feet of the surface. The rock wells yield abundant waters of much the same character as that from the limestone in other parts of the county.

Swayzee.—Swayzee is supplied by a large number of private wells, most of which are drilled into the limestone. The limestone lies from 18 to 41 feet below the surface, and abundant water is almost always found in it. The average rock well is about 100 feet deep and 2 inches in diameter. A few dug wells are still in use, and obtain water from the till above the rock, but there is always danger that the water from such wells will become polluted, especially in towns, and they should, wherever possible, be abandoned in favor of the deeper, tubular wells.

Other communities.—A list of other villages in Grant County, with particulars regarding their water supply, is given in the following table:

Other village supplies in Grant County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Arcana	50	Wells, drilled and dug	20	120	90	220	−40	Gravel.
Farrville	28	Wells, drilled	25	120	100	95	.....	Limestone and gravel.
Fowlerton	53	Wells, dug and drilled	15	200	100	170-200	.....	Do.
Hackleman	82	.....do	20	40	30	20	−10	Limestone.
Hanfield	100	.....do	10	200	15	400	.....	Gravel, till, and limestone.
Herbst	100	.....do	10	120	10	18	− 8	Gravel and limestone.
Jadden	35	.....do	14	100	85	300	−35	Gravel.
Jalapa	90	.....do	40	60	50	30	−5 to+ 3	Limestone and gravel.

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Other village supplies in Grant County—Continued.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Landess	194	Wells, dug and drilled	10	150	18	140	.....	Gravel and limestone.
Mier	219	do	15	104	60	13–26	−20	Do.
Normal	50	do	18	34	18	98	−12	Gravel.
Point Isabel	169	do	20	125	60	40	−12	Clay and limestone.
Puckett	11	Wells, drilled	90	100	90	185	−60	Gravel.
Radley	30	do	20	45	35	20	.....	Limestone.
Rigdon	178	Wells, dug and drilled	20	50	30	30–40	−8 to −20	Gravel and limestone.
Roseburg	90	Wells, dug, driven, and drilled.	10	50	.....	.....	− 5	Do.
Sims	160	Wells, drilled and dug	10	105	60	35–60	−15	Do.
Sweetsers	50	do	15	102	60	20–45	−10	Till and limestone.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Grant County and analyses of their waters. The number in the last column in each table refers to identical wells in the other table.

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Records of typical wells in Grant County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*In.*	*Feet.*	*Feet.*		*Feet.*	*Galls.*	*°F.*	
1	Joshua Strange	Arcana	88	Drilled	3	88	−40	Gravel				1
2	Public supply	Fairmount	40	do	4	40		Limestone	20			2
3	do	do	90	do	6	90		do	20			
4	T. H. Snider Preserve Co	do	166	do	6		− 8	do				
5	E. D. Fowler	Fowlerton	103	do				Sand and gravel.				3
6	Public supply	Gas City	325	do	8			Limestone				4
7	U. S. Glass Co	do	185	do	6	180	−30	do	160			
8	American Steel and Tin Plate Co	do	400	do	8	200	−80	do	190			
9	Sarah Baker	Hanfield	200	do				Gravel				
10	Joseph Lewis	Herbst	11	Dug				Quicksand				6
11	Wm. R. Brock	Jalapa	62	Drilled	8	62	+ 5	Limestone	9			
12	C. P. Marks	do	25	Dug		25		Gravel				7
13	Public supply	Jonesboro	25	do			− 3	do				8
14	German Baptist Church	Landess	24	do		24		do				9
15	Public supply	Marion	120-250	Drilled	8	120-150	+ 8	Limestone	80-150			10,12,15
16	Matter Park well	do		do	8		+ 2	do	2	500		16
17	Fred H. Weir	do	42	Driven	2	42	+20	Gravel		1½	52	17
18	Indiana Brewing Association	do	100	Drilled	3			do				
19	do	do	372	do	8			Limestone				
20	Marion Paper Co	do	150	do	8		+	do	4			
21	do	do	287	do	10		+	do	4			
22	Mrs. David Overman	do		do	8		+ 3	do	225	½	52	18
23	Zirkle Bros	Matthews	65	do	3		−40	Sand				19
24	Mrs. M. Johns	Point Isabel	125	do	4			Limestone	40			20
25	Mrs. J. W. McLain	Sims	105	do	2			do	38			
26	Wm. Larkens	Swayzee	98	do	3			do	36			21
27	J. H. Surface	Sweetsers	80	do	4	80		do	40			22
28	Public supply	Upland	240	do	6	226	−80	do	198			
29	E. S. Sutton	Vanburen	195	do	8	175	−15	do	140			23
30	Mrs. John Heffner	do	65	do	2		−	Gravel				24

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Mineral analyses of waters in Grant County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Joshua Strange	Arcana	Drilled well, 88 ft. by 3 in.	H. E. Barnard.	Oct., 1907	Limestone	....	0.40	....	90	45	.....	.....	0.0	263	642(?)	8	0.30	0.001	0	730	1
2	Public supply	Fairmount	Drilled wells, 40 to 90 ft.	.....do.....	.....do.....	.....do.....	....	.0	....	124	41	.....	.....	.0	352	290	68	.05	.00	2	736	2
3	E. D. Fowler	Fowlerton	Drilled well, 103 ft.	.....do.....	Nov., 1907	Gravel	....	1.2	....	61	28	.....	.....	.0	322	34	2.0	.00	.050	4	448	5
4	Public supply	Gas City	Drilled well, 325+ ft.	.....do.....	Oct., 1907	Limestone	....	.08	....	38	30	.....	.....	.0	305	84	6.0	.20	.004	0	558	6
5	.....	Hanfield, Ind	10 oil wells	.....do.....	Nov., 1907	.....	....	.4	....	615	370	.....	.....	.0	428	392	7,640	.00	.001	33	17,604	....
6	Joseph Lewis	Herbst	Open well, 11 ft.	.....do.....	Oct., 1907	Sand	....	.3	....	157	37	.....	.....	.0	286	248	77	.05	.00	4	662	10
7	C. P. Marks	Jalapa	Open well, 25 ft.	.....do.....	...do.....	Gravel	....	.01	....	94	27	.....	.....	.0	268	154	40	3.0	.00	0.0	576	12
8	Public supply	Jonesboro	Open well, 25 ft. by 15 ft.	.....do.....	...do.....	.....do.....	....	.80	....	40	37	.....	.....	.0	311	128	5	.00	.00	2	464	13
9	German Baptist Church.	Landess	Open well, 24 ft.	.....do.....	Nov., 1907	.....do.....	....	.20	....	95	41	.....	.....	.0	296	82	7	.00	.00	4	542	14
10	Old public supply	Marion	Wells, 68 ft	E. T. Cox	1877	.....	28	12	3.2	114	38	1.80	32	217	....	47	4.1	.....	.....	.....	.....	....
11	Pennsylvania R. R. Co.	.....do.....	Wells	Pennsylvania R. R.	.....	.....	14	.12		72	34	8.7		191	....	4.2	10	.....	.....	.....	364	....
12	Old public supply	.....do.....	Drilled wells	(a)	1897	Gravel	....	Tr.	....	123	31	.....	.....	.....	.....	26	12	.00	.....	.....	432	....
13	.....do.....	.....do.....	Wells in gravel	(a)	1897	.....do.....	....	Tr.	....	169	49	.....	.....	.....	.....	127	37	.00	.....	.....	830	....
14	.....do.....	.....do.....	Drilled well in rock.	(a)	1906	Limestone	....	Tr.	....	107	38	.....	.....	.....	.....	29	71	.00	.....	.....	535	....
15	Public supply	.....do.....	Drilled well, 106 ft. by 8 in.	R. B. Dole	Sept., 1907	.....do.....	27	.97	....	69	35	28		.0	322	36	24	0.4	.....	.....	371	....
16	Matter Park Well	.....do.....	Drilled old gas well.	.....do.....	...do.....	.....do.....	21	1.5	....	79	43	55		.0	321	158	28	1.3	.....	.....	569	16
17	F. H. Weir	.....do.....	Driven well, 42 ft. by 8 in.	H. E. Barnard.	Nov., 1907	Gravel	....	1.0	....	102	40	.....	.....	.0	390	166	6.0	.10	.00	4	548	17

[a] First Scientific Station for the Art of Brewing, New York City.

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Mineral analyses of waters in Grant County—Continued.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
18	Mrs. David Overman.	Marion.....	Drilled well, 225 ft.	H. E. Barnard.	Nov., 1907	Limestone	....	1.4	....	70	29	.....	.....	0.0	320	35	8.0	0.30	0.00	9	418	22
19	Zirkle Bros.....	Matthews...	Drilled well, 65 ft. by 3 in.	.....do.....	...do.....	Sand.....	....	1.0	....	86	31	.....	.....	.0	362	45	5.0	.10	.00	6	504	23
20	Mrs. M. Johns.....	Point Isabel	Drilled well, 125 ft. by 4 in.	.....do.....	...do.....	Limestone	....	0.6	....	59	30	.....	.....	.0	306	138	3.0	.05	.00	2	492	24
21	Wm. Larkens	Swayzee....	Drilled well, 98 ft. by 3 in.	.....do.....	Oct., 1907	.....do.....	....	.4	....	124	38	.....	.....	.0	326	373	8.0	.15	.01	2	448	26
22	J. H. Surface.....	Sweetsers...	Drilled well, 80 ft. by 4 in.	.....do.....	...do.....	.....do.....	....	.1	....	71	32	.....	.....	.0	335	44	8.0	.15	.00	0.0	458	27
23	E. S. Sutton.....	Vanburen...	Drilled well 195 ft. by 8 in.[a]	.....do.....	Nov., 1907	.....do.....	....	2.0	....	126	29	.....	.....	.0	335	180	5.0	.10	.00	9	742	29
24	Mrs. J. Heffner.....	.....do.....	Drilled well, 65 ft. by 2 in.	.....do.....	...do.....	Gravel.....	....	2.4	....	111	30	.....	.....	.0	349	167	6.0	.10	.00	9	622	30

[a] Water from 175 feet.

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HAMILTON COUNTY.

SURFACE FEATURES AND DRAINAGE.

Hamilton County is in the southern part of the area under discussion, in the middle north-south tier of counties and in the second tier from the south edge. The county is square, measuring about 20 miles on each side, and had in 1900 a population of 29,914, or an average of 74 people to the square mile.

The county has a total range in elevation of somewhat over 150 feet. The lowest point is at the edge of Marion County, in the White River valley, and the highest portion is in the northwest corner, where the surface lies over 900 feet above sea level. The surface is for the most part a high till plain which has been more or less dissected by streams. Only two streams are large enough to have excavated well-developed valleys. (See Pl. I.) A low, broad belt of moraine runs north and south along the west edge of the county, and in places resembles closely in topography the surrounding till plains.

The surface forms of the entire county are determined by the glacial deposits and by the streams, for the rock is everywhere so deeply covered that its irregular surface has no influence upon the present topography.

White River controls the drainage of the county, and entering it from the east flows west and south to cross the south county line at about the middle. The valley is well developed and the stream is bordered by alluvial bottom lands less than a mile in width.

The most important tributary of the White is Cicero Creek, which flows southward to enter the White below Noblesville. Over the remainder of the county there is a network of small streams tributary to the above two, but their valleys are shallow and small.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The search for reliable water-producing beds has led to the sinking of many wells throughout the county, and borings of another class, drilled in the attempt to discover oil and gas, have given much information in regard to the thickness of the surface deposits. There is scarcely a community in which one or two wells have not penetrated to rock. The records of borings show a wide range in the thickness of the surface deposits, and the range is not uncommonly great in short distances. An attempt to show the depth to rock has been made in Plate II, though the results can only be considered approximate, as the records are incomplete. It is certain, however, that before the advance of the glaciers over the county the surface was more rugged than at present, and there were deep valleys which have now been filled.

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The most extensive alluvial deposits of the county lie along the sides of White River in the bottom of the broad valley. They consist for the most part of flood-plain or first-bottom lands which are overflowed by the stream in flood seasons. Above the flood plain there are occasional benches of alluvium, forming terraces below the river bluffs—all that remains of an earlier flood plain. The valley of Cicero Creek also contains less extensive beds of alluvium, as do some of the other still smaller valleys. The deposits increase in importance as the valleys attain greater size. Water is everywhere abundant in alluvium, and many wells are supplied from it. The looseness of the materials permits driven wells to be easily obtained, and the open gravels allow a ready circulation of the water. Where not exposed to pollution the waters are very desirable, and most of the wells are unfailing.

The morainal part of the county, all of which lies along its west edge (Pl. I), is of low relief and contrasts mildly with the topography of the till plain. The moraine waters are contained both in the clay and in the gravel beds. There are many dug wells which penetrate but a little way below the level of the water table and which fail in particularly dry seasons. The drilled and driven wells, which on the moraines go through the morainal deposits into the till below, are much safer from contamination than the open wells and obtain a more reliable water supply.

The till plains comprise more than three-fourths of the surface of the county, and in this area the depth to rock averages much more than 100 feet. In addition to its surface occurrence (Pl. I) the till underlies both the moraines and the alluvium except in the few places in the valleys of White River and Fall Creek where the alluvium lies directly upon the rock. As a result of the wide distribution of the till at the surface and of its great thickness, more wells in this county draw their water from the till than from all other sources. Open or dug wells, into which the water seeps from all levels, are the most common type. These do not generally enter any distinct water bed or encounter any well-defined water channels, and the water seeps slowly out of the clay below the water table. Most dug wells have been used for many years, and few new ones have been sunk during the last decade. The people have now learned that it is possible, by sinking deeper driven or drilled wells, to obtain more permanent and safer waters from the occasional gravel beds in the till, and the use of driven or drilled wells is constantly increasing.

CONSOLIDATED MATERIALS.

The approximate distribution of the various formations as they lie below the surface deposits is shown in Plate III. In the east half of the county the "Niagara" limestone is the first rock formation encountered, and although the surface of the till plain is very uniform,

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The depth to rock varies greatly from place to place. The rock surface was first carved by the preglacial streams, then modified by the erosion of the glacial ice, and finally leveled over by the glacial deposits.

As determined by well borings, the "Niagara" is here of the same character as it is farther north. It outcrops at only a few points in the valley of White River above and below Strawtown and in the valley of Fall Creek. In the White River and Fall Creek valleys and in the neighborhood of Clarksville and Fishers Switch this limestone is close enough to the surface to be available for its water supply. Many wells draw upon the rock waters, the joints and bedding planes yielding abundant water of good quality, as it is protected from pollution from above by the thick mantle of drift.

The Devonian beds that lie immediately below the till in the west half of the county nowhere outcrop at the surface, but are known to consist largely of limestones, with the New Albany shale probably occurring in the extreme southwest corner. The same formations outcrop in Carroll County, and are described with the rocks of that county. At Westfield and Carmel and in the surrounding country many wells that extend into the Devonian limestones obtain abundant waters, which are in many places under artesian pressure, especially in Clay Township. There is but little possibility that rock waters from such depths could contain harmful organic matter, and they have always been considered a most satisfactory supply.

ARTESIAN AREAS.

There are seven separate areas in the county in which flowing wells occur. These are outlined and numbered on Plate IV, and are described separately below.

Clay Township, in the southwest corner of the county, has many fine flowing wells. (Pl. IV, No. 29.) The area in which they occur is in the lowlands bordering Williams Creek and its tributaries. In this neighborhood the Devonian limestones lie about 140 feet below the surface, and the flowing waters found in the upper part of the limestone or in sand or gravel immediately above it will in many wells rise 7 or 8 feet above the surface. All flows are found in the lowlands. On higher ground the same waters occur in the rock, but the head is not sufficient to give flowing wells. A moraine extends along the west edge of the county, and the wells penetrate much gravel before rock is reached. The head of the flowing waters is probably in the higher land of this moraine, the waters passing through open gravel beds into the limestone, while the head of the water is maintained by the impervious beds of clayey drift.

Flowing wells occur in the creek valley, 5 miles west of Cicero. (Pl. IV, No. 30.) The artesian water, which has a temperature of 51½° to 52° F., is from the "Niagara" limestone, which here lies

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below 150 to 170 feet of clayey till. Doubtless other flowing wells could be obtained along this creek bottom by drilling into the limestone.

In Westfield the shallow flowing wells, which are located in the lower parts of the town (Pl. IV, No. 31), are all driven into gravel to depths of 14 to 35 feet, and the flows are weak, usually less than 1 gallon a minute. The temperature of the water in one well was found to be 54° F. The waters are protected above by clay, and should be free from pollution. The source of the waters is probably in the slightly higher moraine to the west.

In flowing-well area No. 32 (Pl. IV), which lies along the valley of Stony Creek in the east part of the county, the artesian waters are from the "Niagara" limestone, which is here covered by 40 feet of pebbly till. It was necessary to drill 75 feet into the rock in one well before large enough openings were encountered to give a good flow.

A few flowing wells have been obtained along the valley of White River and its larger tributaries in White River Township (Pl. IV, No. 33), the strongest of which, an abandoned gas well, belongs to E. P. Whisman, and is 1½ miles north and 1 mile east of Strawtown. The water is from the "Niagara" limestone, and will rise 9 feet above the surface. The record of this well, so far as known, is No. 14 in the table on page 136. Its strong pressure indicates that other wells in the lowlands in this section of the county should also obtain flows.

Two miles west of Arcadia there are flowing wells in the lowlands. (Pl. IV, No. 34.) One is a driven well, 61 feet deep, and another a dug well, 16 feet deep, and both are supplied from gravel or sand beds below the till. Another well, on the farm of E. A. Hollett, enters gravel at 65 feet and is reported to have a strong flow of water, which will rise 14 feet above the surface. The conditions of flow are local and can not be expected to obtain for more than a short distance up and down stream from the above wells. Records of two of these wells are Nos. 3 and 4 in the table on page 136.

In the valley of Duck Creek, near Aroma, are two flowing wells (Pl. IV, No. 35), one of which (No. 5, p. 136) was drilled for water to a depth of 80 feet and is reported to have gone into the rock. The other is an abandoned gas well and its flow certainly comes from the "Niagara" limestone.

Several flowing wells have been obtained in the lowlands west of Cicero. (Pl. IV, No. 36.) In these wells, all of which are deep borings drilled for oil or gas, the flows come from the "Niagara" limestone, which is first entered at about 90 feet below the surface, though the flowing waters are encountered at depths of 300 to 500 feet. The largest flow is about 60 gallons per minute. (See No. 15, p. 136.)

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CITY AND VILLAGE SUPPLIES.

Noblesville.—The Noblesville public waterworks, owned by the Noblesville Water and Light Company, were first operated in 1892, and the water is drawn from drilled wells, of which the company owns 17. Of the two that penetrate limestone, one was drilled for gas but is now used for its water supply, while the other, 390 feet deep, entered rock at about 80 feet. The two rock wells will yield 750,000 gallons per day. Of the other 15 wells, of which only 9 are now in use, all enter gravel at 60 to 85 feet. The record of the materials penetrated by one of these wells is as follows:

Log of well drilled for Noblesville Water and Light Company.

	Feet.
Soil and clay	4½
Dry gravel	13
Blue clay (hardpan)	20
Water, sand, and gravel	9
Yellow and blue hardpan	6
Water gravel	8
Fine packed sand	12½
	73

Analyses of the water from the gravel wells in 1906 and early in 1907 showed indications of surface pollution. Steps have now been taken to prevent the entrance of surface drainage by cementing around the joints of the pipes.

The rock wells are pumped by an air lift into a 50,000-gallon reservoir, and the water from this reservoir and from the gravel wells is pumped into the mains by direct pressure. There are 750 taps supplied by 13 miles of mains, and more than one-third of the people use this supply. The average daily consumption of water from this source is 480,000 gallons.

About 65 per cent of the people in Noblesville are supplied from privately owned wells, the greater number of which are drilled. The wells have considerable range in depth, determined in part by the depth to the rock, which is from 33 to 175 feet below the surface. Most wells are in gravel, though some obtain rock waters. At the Model mill a well was drilled through the following materials:

Log of well at Model mill, Noblesville.

	Feet.
Gravel	44
Clay	18
Sand	3
Clay	4
Sand	8
Coarse water-bearing gravel	7
Fine water-bearing sand	7
Clay	4
Sand	8
Limestone	6
	108

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A deep gas well, the Banner well, had the following section:[a]

Log of Banner gas well, Noblesville.

	Feet.
Drift	73
Niagara limestone and shale	265
Clinton (?) limestone	30
Hudson River and Utica	476
Trenton limestone	9
	853

Sheridan.—In Sheridan the waterworks system, owned by G. H. Farmer, supplies about 25 services. The water is drawn from two driven wells, 150 and 135 feet deep, and pumped to a tank 65 feet high, which has a capacity of 300 barrels. From the tank it is distributed by gravity. About 300 barrels per day are used. Both wells are driven to gravel beds, and the water is fairly soft.

Most of the wells in Sheridan are driven or dug. The dug wells which procure water from a gravel bed at a depth of 30 feet or less are unsafe and should be abandoned, for they receive surface drainage as well as gravel water and are likely to be polluted. The driven wells that enter deeper gravels are much safer. The rock here lies 200 feet beneath the surface, and the expense of sinking drilled rock wells for domestic supplies is often prohibitive.

Cicero.—At Cicero, which lies on a flat plain, the till is 160 feet thick, and few wells enter rock. The private wells, of which there are a large number, are dug and drilled and obtain water from the till and from the inclosed gravel beds. The dug wells range in depth from 10 to 40 feet, and their water is all drawn from gravel or sand beds in the till. In the lowlands along the creek there are many good springs and some flowing wells. (See Pl. IV, No. 36.)

Arcadia.—In Arcadia the wells are dug or drilled and range in depth from 10 to 212 feet. The surface deposits are here so thick that few wells reach rock, though a few enter limestone at depths of 130 to 205 feet and yield an admirable supply for most purposes. The common depth for wells is about 20 feet, and the dug wells predominate in spite of the danger from their use. The water obtained from sand and gravel is abundant and even the shallow wells seldom fail.

Atlanta.—Atlanta has no public waterworks, and private wells are relied upon for the water supply. Many shallow wells of the open or dug type and from 10 to 30 feet in depth are used, and although these supply unfailing water their sanitary condition is doubtful. The drilled wells are deeper, and as all the surface waters are cased off they draw their supply only from the well bottom, from 50 to 130 feet below ground. No rock is struck at depths less than 220

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 253.

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to 300 feet, and there are no wells in this town supplied by rock waters.

Other communities.—In the following table is a list of other villages in Hamilton County, with particulars of their water supply:

Other village supplies in Hamilton County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Aroma	110	Wells, dug and drilled.	10	125	50	102	.....	Gravel and limestone.
Bakers Corners.	60	Wells, dug, driven, and drilled.	15	140	18	.....	.....	Gravel.
Boxley	204	Wells, driven and dug.	20	70	50	.....	15	Do.
Carmel	498	Wells, dug, driven, and drilled.	30	112	100	100	12	Gravel and limestone.
Clarksville	160	Wells, dug and drilled.	10	75	30	18	8	Limestone.
Deming	154	.....do.....	10	142	20	.....	.....	Gravel.
Durbin	22	Wells, driven, dug, and drilled.	15	90	30	.....	.....	Gravel and limestone.
Eagletown	275	Wells, driven and dug.	16	200	20	200	15	Gravel.
Fishers Switch.	200	Wells, dug, driven, and drilled.	25	100	25	100	.....	Gravel and limestone.
Horton	193	.....do.....	10	125	15	240	.....	Gravel.
Joliet ville	231	Wells, dug and driven.	20	100	25	.....	12	Do.
New Britton	101	Wells, dug, driven, and drilled.	10	110	15	.....	.....	Do.
Omega	94	Wells, dug and drilled.	10	200	100	280	.....	Do.
Strawtown	89	.....do.....	25	112	75	50	.....	Limestone and gravel.
Westfield	670	Wells, dug, driven, and drilled.	20	182	25	200	0–6	Do.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Hamilton County and analyses of their waters. The last column of each table gives numbers referring to identical wells in the other table:

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Records of typical wells in Hamilton County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Feet.*	*Galls.*	°*F.*	
1	Town well	Arcadia	163	Drilled	4	163	−25	Gravel				1
2	do	do	177	do	4	177	−20	Limestone				2
3	F. F. Noble	2 miles W. of Arcadia	16	Dug		16	+	Sand				
4	do	do	61	Drilled		61	+	Gravel				
5	Charles Harvey	Aroma	80	do		80	+ 4	do		2		
6	Schoolhouse	Atlanta	120	do	4	120	−	do				3
7	A. E. Jessup	4 miles SW. of Carmel	160	do	3	152	+ 7			3	52	
8	O. C. Elliott	3 miles SW. of Carmel	150	do	8	150	+ 2	Limestone				
9	J. A. Newby	do	140	do	2½	130	+ 4	Sand	135	1		
10	Micah Newby	4 miles SW. of Carmel	140	do	3		+ 8	Limestone	135			
11	J. R. Carson	Cicero	86	do			−16	Gravel				5
12	Geo. Foulke	5 miles W. of Cicero		do			+ 4	Limestone	160	10	51½	7
13	Charles H. Dole	Cicero	42	Dug		42		Sand and gravel.				6
14	E. P. Whisman	6 miles NE. of Cicero		Drilled	8		+ 9	Limestone		20		
15	C. B. Sherer	½ mile NW. of Cicero	1,584	do	8¾	486	+ 3½	do	90	60		
16	A. L. West	Fishers Switch	95	do	3	95	−30	Gravel				
17	Charles Randall	¼ mile N. of Fishers Switch	92	do	3	90		do				
18	Noblesville Water and Light Co.	Noblesville	345	do	8	350	−25	Limestone	− 80			9
19	do	do	60–85	do	8		−25	Gravel				8
20	Excelsior Laundry	do	178	do	4	174	−27	Limestone	172			
21	Nordyke & Marmon	do	108	do	6	75		Gravel				
22	Martha F. Hair	4 miles E. of Noblesville	115	do	8	115	+ 4	Limestone	40			
23	Schoolhouse	Sheridan	150	Driven	2	150		Gravel				11
24	W. W. Morris	Strawtown	112	Drilled	3			Limestone				12
25	Frank Hussey	5 miles E. of Zionsville	153	do	3	152	+ 8	do	147	4		

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Mineral analyses of waters in Hamilton County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg)	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Public well	Arcadia	Drilled well, 163 ft. by 4 in.	H. E. Barnard	Nov., 1907	Gravel		0.12	80	24			0.0	272	15	6.0	0.50	0.000	9	350	1
2	do	do	Drilled well, 212 ft. by 4 in.	do	do	Limestone		.40	80	25			.0	280	20	4.0	.25	.001	19	384	2
3	Schoolhouse well	Atlanta	Drilled well, 120 ft. by 4 in.	do	Oct., 1907	Gravel		.40	81	65			.0	323	97	60	.30	.000	0.0	370	6
4	Stockyards well	Cicero	Well, 110 ft. by 4 in.	Lake Shore and Michigan Southern R. R.	Dec., 1904				81	29	17		194		5.9	22					
5	Dr. J. R. Carson	do	Drilled well, 86 ft.	H. E. Barnard	Nov., 1907	Gravel		.80	170	25			.0	344	20	12	.001	1.2	23	362	11
6	Charles H. Dole	do	Open well, 17 ft.	do	do	do		.00	256	71			.0	416	665	140	.05	.000	22	1,284	13
7	George Foulke	5 miles W. of Cicero.	Drilled well, 169 ft.	do	do	Limestone		1.4	79	27			.0	260	15	18	.20	.000	19	442	12
8	Public supply	Noblesville	Drilled wells, 60 to 85 ft.	R. B. Dole	Aug., 1907	Gravel	20	2.0	84	31	19		.0	352	32	16	2.8			376	19
9	do	do	Drilled well, 345 ft.	do	do	Limestone	21	3.0	82	30	18		.0	372	22	17	.04			375	18
10	Taylor & Sons	do	Well, 27 ft.	Lake Erie and Western R. R.					112	35	17		188		70	25	39				
11	Schoolhouse	Sheridan	Driven well, 150 ft. by 2 in.	Chase Palmer	Aug., 1907	Gravel	21	1.8	61	27	47		Tr.	431	5.6	1.5	4.0			396	23
12	W. W. Morris	Strawtown	Drilled well, 112 ft. by 3 in.	H. E. Barnard	Nov., 1907	Limestone		3.0	94	10			.0	278	9 1	7	1.10	.000	13	438	24

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HANCOCK COUNTY.

SURFACE FEATURES AND DRAINAGE.

Hancock County occupies the extreme southeast corner of the area covered in this report. It is irregular in outline and has an area of 290 square miles. As the population in 1900 was 19,189, there was an average of 66 inhabitants to the square mile.

This is essentially an upland county and is more uniformly a high plateau than any other portion of north-central Indiana. In the neighborhood of Wilkinson the surface, though of mild relief, lies more than 1,000 feet above sea level; the extreme northwest corner has an elevation of 800 feet. This plateau is composed of glacial deposits. The north and northwest portions are a till plain, but a low moraine belt covers the south and southeast parts of the county, which lies on the divide between White River on the west and Blue River on the east. The form of the underlying rock surface has had no influence on the present relief of the county. No outcrops occur, and the glacial deposits range from 100 to 300 feet in thickness.

Stream cutting has played a comparatively unimportant part in shaping the surface of this high plain. The only important valley is that of Big Blue River, which crosses the southeast corner of the county. Its valley is about 50 feet below the bordering uplands and contains a wide flood plain. Next in size is Sugar Creek, which crosses the county from northeast to southwest, with a valley which varies from only a few feet in depth at the upper end to 30 or 40 feet below New Palestine. The river flat has nowhere been greatly widened. The only other noteworthy stream is Brandywine Creek, which flows south through Greenfield. The creek lies from 20 to 30 feet below the plain and its flood plain is narrow.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

As will be seen from an inspection of Plate I, the surface deposits of Hancock County are almost equally divided between plains of pebbly till and morainal drift. Alluvial beds of sufficient extent to show on a map of this scale occur only in the valley of Big Blue River. Plate II shows the thickness of the surface deposits throughout the county. As they are nowhere less than 90 feet thick, it follows that by far the greater number of wells procure their supply from the glacial drift above the rock.

The alluvium in the valley of Big Blue River consists of flood-plain and terrace deposits of gravels, sands, and silts. During the retreat of the last great glacier from this region, the Blue River valley afforded one of the important channels of escape for the

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›undant waters of the melting ice, and along it there were deposited tensive beds of fluvio-glacial débris. The valley is much larger an the present stream would have developed, and the alluvial de›sits are more extensive than those left by the postglacial streams similar size. The thickness of the valley deposits varies but ›nerally falls between 20 and 40 feet. Along Sugar and Brandyine creeks the alluvial beds are more restricted in area and are ›mmonly 15 to 25 feet thick. The valley gravels carry abundant ater obtained from the rainfall and from the seepage of the sur›unding uplands. Wells are easily obtained, the simplest and most ›mmon type being the driven well, 10 to 30 feet in depth. These ells give large yields if ended in coarse gravels, and the water, though ard, is softer than that either from the till or the limestones. There re many wells in alluvium along the Blue River valley and in the lats of Brandywine, Sugar, and the smaller creeks.

The southeast half of this county is moraine covered, the surface ›onsisting of low, rolling hills, 20 or 30 feet high, with many scattered ›owlders. There are no sharply defined ridges or areas of strong relief, and in this the moraine differs greatly from the great moraine belts in the northern part of the State. The surface deposits reach great thickness wherever the moraines lie on top of the till, and at Cleveland a well was drilled 240 feet deep before it entered rock. The water supplies of the moraine are much like those of the till, as the materials are nearly identical. Dug wells predominate, but driven and drilled wells are numerous.

In the northern till-covered half of the county the surface is plain-like and rises gradually from the west to the east edge. The thickness of the till seems to be fairly uniform from west to east, the rock surface below rising at about the same slope as the till surface. The stream valleys are all very shallow, and the topography is remarkably uniform and featureless. The clayey till itself furnishes water to a large number of shallow dug wells, the water entering through the loose-curbed walls as it seeps out slowly from the clay. An increase in the amount of gravel in the clay increases the supply of water, and distinct beds of gravel almost everywhere yield rather abundant supplies. Deep driven or drilled wells generally reach some such gravel beds, and few of them enter the underlying rock. Good sanitary protection is given to the deeper gravels by the overlying clays.

CONSOLIDATED MATERIALS.

The "Niagara" limestone outcrops beneath the drift in northeast Hancock County, though it is everywhere deeply covered by the surface deposits. It has been reached by the drill at Fortville, Melners Corners, Wilkinson, and Willow, and its character is evidently much the same as in the area to the north, where it comes to the surface.

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Deep drillings throughout the entire county pass through the "Niagara," though in the south, central, and west portions it is overlain by the Devonian beds. All wells entering the "Niagara" obtain abundant water, usually in the upper portion of the formation.

Little is known of the character of the Devonian limestones, which are the uppermost rocks in the south and west portions of the county (Pl. III). The records of drillers commonly class them with the "Niagara." The Devonian beds are reliable water producers, no failure to obtain abundant water in the limestones having been recorded. The water occurs in the fractured and somewhat weathered upper portion of the rock or in the deeper joints or bedding planes.

ARTESIAN AREAS.

One artesian area (Pl. IV, No. 37) includes the lowlands along Brandywine Creek near Greenfield, where there are a number of flowing wells, all of which are drilled into limestone. Two are old gas wells, one on the property of W. S. Freeze (No. 6, p. 142) and one in the flat of Brandywine Creek. It is not known at what depth the flowing water was encountered, except that it is from the limestone, which is here about 150 feet below the surface. The only other flowing wells in this area, eight in number, are at the Greenfield city waterworks. When these wells are pumped the head is lowered below the surface of the ground. The wells are "in sympathy" with the flowing well at the creek bottom, which ceases to flow when the city wells are being pumped. Although the water is found in the Devonian limestone, the head is probably from waters in the underlying "Niagara" limestone. The "Niagara" beds rise toward the east, the direction of the Cincinnati arch, and the flowing waters probably come down this structural slope.

A number of other flowing wells from abandoned gas borings are reported to occur along the Brandywine south of Greenfield.

There are two flowing wells at New Palestine, both on the property of Mr. Max Herrlick. The records of the wells are lost, but they are reported to have entered rock at 285 feet and to be 1,000 feet deep. The flowing water is said to have been encountered at a depth of 200 feet. The water rises 15 feet above the surface, and is carried to a hydraulic ram which pumps 13,000 gallons per day. The water is used for the public supply. Other flowing wells could certainly be obtained in the near-by lowlands if carried to sufficient depth.

One mile north of Melners Corners, in the valley of Sugar Creek, there is a flowing well on the farm of W. A. Collingwood. (Pl. IV, No. 39.) The water is obtained from gravel at a depth of 20 feet, and the flow fills a 1¼-inch pipe. The conditions for flow are local, but wells in the creek valley near by would also probably strike flowing waters.

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CITY AND VILLAGE SUPPLIES.

Greenfield.—The city of Greenfield owns and operates waterworks, which were established in 1894 at the east edge of the town. The water, drawn from eight flowing wells (Pl. IV, No. 37), is from the limestone and is pumped directly into the mains from the wells, a domestic pressure of 45 pounds being maintained, while for fire protection the pressure is increased to about 100 pounds. There are over 8 miles of mains and 900 taps, and about 75 per cent of the people use this water. About 300,000 gallons per day are pumped.

In Greenfield there are still large numbers of private wells in use. The dug wells formerly were more numerous, but they are gradually being abandoned and their places taken by driven wells. In the north and northeast parts of the town water-bearing gravels are found at about 45 feet below the surface, while in the south part of town it is necessary to sink wells to a little over 100 feet before good supplies are obtained. Before the city supply was installed many dug wells were used, and typhoid fever was prevalent. No case of this disease has been reported from families which use only the city water.

New Palestine.—The public supply of New Palestine is owned by Max Herrlick. The water flows from the artesian wells already described (Pl. IV, No. 38), and a part of the flow is pumped by hydraulic ram to a tank 86 feet above the wells, which has a capacity of 6,000 gallons. From the tank the water is distributed by gravity to about 2 miles of 2-inch iron mains, and 35 taps are supplied. There are no connections with this system for fire protection.

The private wells are dug and driven. The dug wells range in depth from 14 to 24 feet, and the driven wells from 30 to 125 feet. The common depth for driven wells is 65 feet, and a good bed of water-bearing gravel can almost everywhere be found at that depth.

Fortville.—In Fortville all the open wells have been abandoned, and drilled or driven wells are used altogether. In the town there are perhaps six or eight wells which reach rock, and they all have abundant water. An analysis of water from the limestone, which here lies at a depth of about 165 feet, is No. 3 in the table on page 143. The driven wells are sunk either to first or second gravel, first gravel being reached at 10 to 35 feet, and second gravel at 70 to 80 feet below the surface. Most wells obtain water of good quality from second gravel at an average depth of 70 feet.

Charlottesville.—Charlottesville has no public supply, and each home has a private well from which its water is drawn. Dug wells were formerly numerous, but these are being abandoned and driven or drilled wells substituted. Gravel, encountered at depths of 30 to 85 feet, furnishes safe and abundant waters, which rise within 15 feet of the surface. In the town rock lies 170 feet below the glacial beds, and no rock waters are used.

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Other communities.—The following table contains a list of other villages in Hancock County, with details regarding their water supply:

Other village supplies in Hancock County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Cleveland	125	Wells, dug and drilled.	12	240	200	240	.....	Sand and gravel.
Eden	100	.....do.....	20	30	20	.....	.....	Gravel.
Gem	80	.....do.....	20	150	130	.....	.....	Sand and gravel.
Maxwell	300	Wells, driven and drilled.	40	278	.....	276	.....	Gravel and limestone.
McCordsville	301	Wells, dug and drilled.	14	132	15	100	6	Gravel.
Meiners Corners	.....	Wells, driven and drilled.	9	100	20	100	3-10	Do.
Mohawk	162	Wells driven.....	20	35	30	.....	15	Do.
Mount Comfort	134	.....do.....	20	40	30	.....	.....	Do.
Philadelphia	182	Wells, dug and driven.	25	80	75	.....	.....	Sand and gravel.
Shirley	381	Wells, drilled, bored, and dug.	40	138	50	170	.....	Gravel.
Warrington	200	Wells, dug and driven.	10	30	25	.....	.....	Do.
Wilkinson	208	Wells, drilled, driven, and dug.	30	180	.....	.....	.....	Gravel and limestone.
Willow	127	Wells, dug and driven.	20	80	.....	180	5-10	Sand and gravel.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Hancock County and analyses of their waters. The last column of each table gives numbers referring to identical wells in the other table.

Records of typical wells in Hancock County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Analysis No.
			Feet.		*In.*	*Ft.*	*Feet.*		*Ft.*	*Gals.*	
1	C. Vannlaningham	Fortville	175	Drilled	2½	....	−33	Limestone	165	.....	3
2	L. F. Denney	.....do.....	35½	...do.....	2½	....	−10	Gravel	....	.....	1
3	E. F. Cahen	.....do.....	140	...do.....	2½	....	−30	.....do.....	....	.....	2
4	City waterworks	Greenfield	170	...do.....	8	170	+	Limestone	170	.....	4
5	County jail	.....do.....	200	...do.....	6	200	−30	.....do.....	170	.....	....
6	W. S. Freeze	.....do.....	....	...do.....	6	....	+ 3	.....do.....	....	2	....
7	J. A. Corbin	1½ miles N. of Greenfield.	171	...do.....	4	171	−30	Gravel	....	.....	....
8	Thomas Rash	Maxwell	105	...do.....	4	105	−25	.....do.....	....	.....	....
9	Cleveland, Cincinnati, Chicago and St. Louis R. R.	.....do.....	278	...do.....	8	276	.....	Limestone	276	.....	....
10	E. L. Dobbins	2 miles SW. of Maxwell.	181	...do.....	4	181	−55	Gravel	....	.....	....
11	McCordsville Natural Gas Co.	McCordsville	910	...do.....	....	80	.....	Limestone	....	.....	....
12	S. Morrison	½ mile N. of McCordsville.	100	...do.....	3	100	−30	Gravel	....	.....	....
13	W. A. Collingswood.	½ mile N. of Meiners Corners.	20	Driven	1½	20	+ 6	.....do.....	....	.....	....
14	Frank Welling	3 miles SW. of Mount Comfort.	147	Drilled	2	147	−37	.....do.....	....	.....	....
15	Max Herrlick	New Palestine	1,000	...do.....	6	700	+15	Limestone	....	75	....
16	J. M. Evans	3 miles S. of Oaklandon.	90	...do.....	2½	90	−20	.....do.....	....	.....	....
17	Doctor Chateau	Shirley	138	...do.....	4	138	−30	Gravel	....	.....	....
18	J. Masters	Warrington	200	...do.....	1½	150	−15	.....do.....	200	.....	....
19	Doctor Titus	Wilkinson	187	...do.....	3	180	−20	Limestone	165	.....	....
20	George Condo	.....do.....	180	...do.....	3	180	−20	.....do.....	165	.....	....
21	J. W. Walker	Willow	80	Driven	1½	80	.....	Sand	....	.....	....

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Mineral analyses of waters in Hancock County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.
1	L. F. Denney.....	Fortville....	Drilled well, 35 ft. by 2½ in.	H.E. Barnard.	Oct., 1907	Gravel.
2	E. F. Cahen.....	.....do.....	Drilled well, 140 ft.	.....do.....	...do.....	Do.
3	C. Vannlaningham....	.....do.....	Drilled well, 175 ft. by 2½ in.	.....do.....	...do.....	Limestone.
4	City supply.....	Greenfield...	Drilled wells, 170 ft. by 8 in.	Chase Palmer.	July, 1907	Do.

No.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	.....	0.60	100	21	.....	.....	0.0	172	65	1.0	0.00	0.0	15	280	2
2	.....	.80	74	21	.....	.....	.0	324	26	2.0	.30	.0	0	370	3
3	.....	1.2	73	24	.....	.....	.0	266	23	2.0	.20	.002	2	348	1
4	28	1.2	48	30	23		.0	344	6.2	7.0	1.5	.....	.....	326	4

HENDRICKS COUNTY.

SURFACE FEATURES AND DRAINAGE.

Hendricks County, which lies at the southwest corner of the area covered by this report, is about 19 miles wide and 20 miles long from north to south, though there is a projection which extends 2 miles farther south than the rest of the county. The total area is 408 square miles, and in 1900 the population was 21,292. Danville, the county seat, lies 20 miles west of Indianapolis.

This county occupies a part of the broad plateau between White and Wabash rivers, and most of the drainage belongs to the former stream. The plateau slopes as an inclined plane from the northwest to the southeast corner of the county, and this slope is due more to the preglacial surface as left by the ice than to the influence of post-glacial erosion. The largest valley is that of White Lick Creek, and the lowest point of the county, in this valley, is less than 700 feet above sea level, while the highest, in the northwest portion (Pl. I), reaches a height of over 960 feet, giving the county a total range in elevation of about 275 feet. Most of the surface consists of a level plain, and is, in general, little cut by streams. There is, however, a broad belt of moraine which has a north-south trend and lies somewhat west of the center of the county (Pl. I).

White Lick Creek is the dominating stream, and with Little White Lick and its other smaller tributaries its basin includes almost half of

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the surface. The valley is much deeper than is common for streams of this volume, the excessive development being due to the fact that it discharges into the deep valley of White River, and therefore has the low outlet and steep gradient that are favorable to rapid erosion. The only other streams of importance are Walnut Creek, in the northwest corner, and Mill Creek, in the southwest corner, both of which flow, by way of Eel River, into White River at Worthington.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The principal alluvial beds of the county are found in the valleys of Big and Little White Lick creeks, and to a lesser extent in the valleys of the other streams. Wherever the alluvium attains a thickness of 15 feet or more it is almost certain to furnish plenty of water to dug or driven wells. From the nature of the materials, however, such shallow wells will receive in a short time any sewage which may enter the ground in the vicinity, so that pollution must always be guarded against. The danger is especially great in towns or in the neighborhood of dwellings or barns; hence water for domestic purposes should not be taken from shallow wells so situated. The deeper alluvium, if covered by beds of rather impervious clay, may yield a first-class water supply.

As stated above, a single moraine belt crosses the county from northwest to southeast (Pl. I). North of Danville the surface is rather irregular and rolling, but south of this city the relief becomes milder.

As in the till plains, the open wells predominate. The greater abundance of gravels has favored the construction of driven or drilled wells, and these are constantly increasing in popular favor. The depth varies with the distance to the gravel beds, but it is rarely necessary to sink wells more than 60 or 70 feet.

As shown in Plate I, till plains occupy most of the county surface. The thickness of the material varies greatly, for in the southwest corner the drift is generally less than 75 feet thick, but the depth to rock increases to the north and east until it reaches more than 200 feet in the deepest places. The majority of the wells in the till-plain areas are open or dug and range from 15 to 40 feet deep. The water enters slowly from the till, but in sufficient quantity for ordinary domestic uses. Wells of this type may be obtained almost anywhere, and in the rural districts offer a fairly safe supply if located at safe distances from outhouse and barnyard drainage. In towns they are not safe. Drilled and driven wells have proved very satisfactory, and have demonstrated that gravel beds may be entered anywhere if the wells are continued 75 feet or more. Locally they are found much nearer the surface.

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CONSOLIDATED MATERIALS.

The distribution of the rock formations below the glacial drift is shown approximately in Plate III. The exact line of contact between the Devonian and Mississippian beds in this county can not be determined, because very few wells have penetrated through the drift to them.

The New Albany shale, the uppermost of the Devonian beds, is the oldest rock of the county. Little is known here of the character of its water supply, although in the counties to the east and north it is made up of tight, close-grained beds, which yield little or no water to wells. In Hendricks County the drift above has everywhere yielded sufficient water before the shale is reached.

The "Knobstone" group, of Mississippian age, lies immediately below the drift in all but the northeast portion of this county (Pl. III). These rocks furnish few wells with water in the lower and more shaly portion of the formation. In the southwest half the sandstone of the "Knobstone" comes within 6 or 8 feet of the surface at some places, and wells drilled into it have found plenty of water in the well-defined joints of the rock.

ARTESIAN AREAS.

A flowing-well area lies in the valley of Little White Lick Creek for some distance above and below Danville. (Pl. IV, No. 40.) The best flows have been obtained by the Danville waterworks, where six wells furnish the entire town supply (Pl. VI, *B*). The water is obtained from a gravel bed below till at a depth of 100 to 112 feet, and rises 12 to 22 feet above the surface with an enormous volume. The record of one of these wells is as follows:

Log of well at Danville waterworks.

	Feet.
Sand and gravel	14
Hardpan	5
Blue clay	53
Gravel	40
	112

The gravel beds which yield the flowing waters are of uncertain extent. One well drilled by the Cleveland, Cincinnati, Chicago and St. Louis Railway, one-fourth mile southeast of the Danville pumping station, penetrated hardpan and found no water in or below it. Flowing wells from the drift have also been obtained near Cartersburg in this same artesian area. The Cartersburg Mineral Springs have been described by W. S. Blatchley.[a]

[a] Mineral waters of Indiana: Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1901.

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There is an artesian area in the vicinity of Tilden (Pl. IV, No. 41) where two wells flow at the surface, and where in many wells the water rises within a few feet of the well mouth. The waters are in every well obtained from gravel beds below till, and the wells range from 26 to 114 feet in depth. The record of one of these is No. 14, in the table on page 148.

In artesian area No. 42 (Pl. IV), near New Winchester, a number of flowing wells occur, but by no means all the wells flow. None of the wells are in deep valleys, and many are only 2 or 3 feet below the level of the plain. The water is obtained from the sandstone of the "Knobstone" group, which is entered at 30 to 90 feet below the surface, the overlying till preventing the escape of the waters, and the head may come from the higher part of the formation, a few miles to the north, or from the overlying drift. As no outcrops occur at the surface, the water must reach the rock through gravelly portions of the drift.

An artesian area (Pl. IV, No. 43) at North Salem has a single flowing well, drilled about fifteen years ago in the hope of obtaining oil or gas. The well is 800 feet deep, and the flow is reported to come from a depth of 400 feet, probably from the Devonian limestones. The well flows with a 1¼-inch stream.

CITY AND VILLAGE SUPPLIES.

Danville.—The Danville public water system is owned by the city, and the supply is obtained from six drilled wells in the river valley. There are two 2-inch, two 3-inch, and two 4-inch wells, and each is about 112 feet deep. They have been described above, as in artesian area 40. From the wells, which have a head of 22 feet above ground, the water is pumped to a standpipe with an elevation of 100 feet above the town and 200 feet above the wells, and is distributed from this by gravity. The system has 5 miles of mains and 600 consumers, or about 95 per cent of the total population of the town. About 450,000 gallons per day are pumped. An analysis of this water is No. 4 in the table on page 149. The supply is an excellent one, and it is appreciated by the people, as is shown by the large proportion of users of the city water.

There are very few private wells in Danville. A small number of dug and driven wells are used and some water is obtained from springs along the creek valley.

Plainfield.—Plainfield has no waterworks, and all the water is drawn from private wells. These are dug and driven, are 20 to 25 feet deep, and obtain their water from a bed of gravel. Such a supply is likely to become polluted at any time from the drainage of the outhouses and stables of the town. Deep driven and drilled wells

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are the only safe source of underground waters in such thickly settled communities.

At the Indiana Boys' School, across the creek from the town, the water is obtained from two sources. A fine spring which issues from the side of a gravel terrace supplies the drinking water and a deep well the water used for other purposes. The record of this well was given as follows:

Log of well at Indiana Boys' School, Plainfield.

	Feet.
Soil and brown sandstone	12
Bluestone	58
Bluestone	160
Red shale	18
Brown limestone	52
Limestone	300
White stone	3½
	603½

Pittsboro.—Pittsboro is situated on the till plain about 8 miles northeast of Danville, and has no public water supply. The private wells, whose waters are obtained from gravel beds, are dug and driven, and although they range in depth between 15 and 100 feet as extremes, the common depth is only 20 feet. Such a shallow well supply should be abandoned in favor of deeper tubular wells.

Brownsburg.—The wells of Brownsburg are dug and driven, the former ranging from 15 to 30 feet, and the latter from 30 to 150 feet in depth. The common depth for dug wells is 20 feet and for driven wells 40 feet, and the water, which comes from the till and from gravel beds, rises within 10 or 15 feet of the surface. The driven wells 40 feet or more in depth are probably safe from pollution. The dug wells are open to the same objections stated for wells of this class at Plainfield and Pittsboro, and their waters endanger the health of the community.

Coatsville.—The people of Coatsville depend for their water almost wholly upon dug wells from 18 to 30 feet deep, in which the head of water varies with the seasons. Gravel is entered at about 25 feet. Great care should be exercised to locate wells as far as possible from sources of contamination, and driven or drilled wells are much to be preferred.

North Salem.—The wells of North Salem are dug and driven, and from 15 to 75 feet deep. There is one very deep flowing well, which was described as in artesian area 43 (p. 146). The town is on a till plain, and the only reliable source of supply is the gravel beds in the till. The deep driven wells yield a much safer and more satisfactory water than that obtained from the dug wells, which are likely to be contaminated.

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Other communities.—The following table contains a list of other villages in Hendricks County, with particulars as to their water supply:

Other village supplies in Hendricks County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Amo	325	Wells, dug and driven.	12	30	20	.....	.....	Gravel.
Belleville	268	Wells, dug and drilled.	10	150	40	.....	.....	Do.
Cartersburg	253	Wells, driven and drilled.	40	110	65	.....	20	Do.
Center Valley	92	Wells, dug, driven and drilled.	18	70	30	15	10	Gravel and rock.
Clayton	478	Wells, dug and drilled.	9	140	50	9–60	0–10	Gravel and shale.
Friendswood	110	.....do.....	14	175	70	.....	5	Gravel.
Hadley	68	.....do.....	14	140	30	.....	.....	Do.
Hazelwood	100	.....do.....	10	100	20	20	10	Sand and gravel.
Joppa	40	Wells, dug, drilled, and driven.	15	50	.....	.....	.....	Gravel.
Lizton	347	Wells, dug and driven.	10	150	11–50	.....	2–8	Sand and gravel.
Maplewood	32	Wells, dug	7	30	10	.....	1–5	Gravel.
Mount Clair	.....	.....do.....	10	45	30	.....	.....	Sand and gravel.
New Winchester	116	Wells, dug and drilled.	20	80	25	20–50	.....	Gravel and rock.
Pecksburg	72	Wells, dug	12	30	14	.....	.....	Gravel.
Raintown	50	.....do.....	15	30	20	.....	.....	Do.
Reno	73	.....do.....	12	30	20	.....	.....	Gravel and clay.
Stilesville	357	Wells, dug and drilled.	9	245	20	.....	4–16	Gravel and sandstone.
Tilden	63	Wells, dug and driven.	15	150	20	.....	15	Gravel.

TYPICAL WELLS AND ANALYSES.

The following tables contain detailed information regarding typical wells of Hendricks County and analyses of their waters. The last column in either table gives numbers referring to identical wells in the other table.

Records of typical wells in Hendricks County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Analysis No.
			Ft.		*Ins.*	*Ft.*	*Feet.*		*Ft.*	*Galls.*	
1	Schoolhouse	Amo	225	Drilled	6	.....	.....	Shale	60	.....	...
2	M. T. Hunter	Brownsburg	110	Driven	1¼	110	−20	Gravel	.....	.....	2
3	Public well	.....do.....	22	Dug	.....	20	−18	.....do.....	.....	.....	1
4	W. W. Quinn	Cartersburg	93	Drilled	2	93	−40	.....do.....	.....	.....	...
5	John Tarleton	.....do.....	90	...do.....	.....	.....	.....	.....do.....	.....	.....	...
6	L. C. Vanarsdell	Clayton	56	...do.....	6	40	.....	Shale	6	.....	3
7	Vandalia R. R.	¾ mile W. of Clayton	50	...do.....	6	....	+	Sandstone.	6	.....	...
8	Davis & Johnson	Coatsville	205	...do.....	6	140	− 2	.....do.....	65	.....	...
9	Public supply	Danville	112	...do.....	2, 3, 4	107	+22	Gravel	.....	200	4
10	Charles McLain	2 miles N. of Hadley	68	...do.....	.....	.....	+	Sandstone.	47	.....	...
11	Public well	Jamestown	96	...do.....	1¼	96	− 9	Limestone.	40	.....	5
12	J. N. Lockhart	North Salem	800	...do.....	8	400	+ 8	.....do.....	.....	.....	6
13	Public well	Pittsboro	15	Dug	.....	14	−12	Gravel	.....	.....	7
14	M. H. Arbuckle	¾ mile NE. of Tilden	264	Drilled	2	26	+ 3	.....do.....	.....	3	...
15	Nathan Underwood	S. of New Winchester	57	...do.....	2	....	+ 3½	Sandstone.	40	.....	...
16	Frank Stinson	2 miles E. of Winchester.	96	...do.....	.....	.....	+	.....do.....	70	.....	...

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Mineral analyses of waters in Hendricks County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Public well	Brownsburg	Open well, 22 ft	H. E. Barnard	1907	Gravel		0.10		165	53			0.0	438	242	118	5.0	.001	4	1,066	3
2	M. T. Hunter	do	Driven well, 110 ft. by 1¼ in.	Chase Palmer	Nov., 1907.	do	19	1.8		62	27	37		Tr.	348	2.8	27	.7			405	2
3	Vanarsdell Bros	Clayton	Drilled well, 56 ft. by 6 in.	H. E. Barnard	Sept., 1907.	Shale		.00		355	25			.0	331	67	20	.000	.000	2	408	6
4	City supply	Danville	Drilled wells, 112 ft.	Chase Palmer	July, 1907.	Gravel	16	2.1		32	26	58		.0	360	4.3	3.2	9.0			349	9
5	Public well	Jamestown	Drilled well, 96 ft. by 1¼ in.	H. E. Barnard	1907	Limestone		.20		46	28			.0	378	0.0	38	.20	.001	4	548	11
6	J. N. Lockhart	North Salem	Drilled well, 800 ft. by 8 in.[a]	do	1907	do		2.4		59	27			.0	334	0.0	24	.05	.001	4	404	12
7	Public well	Pittsboro	Open well, 15 ft	do	1907	Gravel		.10		156	58			.0	419	173	172	12.0	.001	0	1,244	13

[a] Water from 400 feet depth.

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HOWARD COUNTY.

SURFACE FEATURES AND DRAINAGE.

Howard County is in the central north-south tier of the group of counties included in this report, somewhat south of its geographic center, and has an area of 295 square miles. Kokomo, the county seat, is 50 miles due north of Indianapolis. The population of the county in 1900 was 28,575.

The county is a part of the high plain between the valleys of White and Wabash rivers, and aside from the valley depression of Wild Cat Creek the surface is monotonously level and featureless. Wild Cat Creek enters the county from the south near the southeast corner and flows northeast and then northwest to Greentown, whence its course is westward through Kokomo to the west county line. The course of the stream in this county is over 40 miles long and the valley is much better developed at the lower than at the upper end. At Burlington, Carroll County, the valley is about 70 feet deep. At Greentown it is less than 30 feet deep, and above it is still shallower. Wild Cat Creek drains all of the south half of the county, and a narrow strip of the plain to the north. From the south it is fed by Honey, Little Wild Cat, and Kokomo creeks. From the north it has no important tributaries.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The important alluvial deposits of Howard County are all confined to the valley bottom of Wild Cat Creek, though there are small areas of alluvium along the courses of its larger tributaries. The valley ranges in width from over one-half mile in the west to a small fraction of this distance at its upper end, and the alluvium varies much in thickness. At Kokomo wells in the bottom lands enter rock after penetrating 20 to 30 feet of gravels and sands. Farther west the thickness increases. In the alluvial bottom lands underground waters are easily obtained. The water table in these areas stands within a few feet of the surface, and the coarse sand and gravel beds furnish large quantities of water. Driven wells, 10 to 30 feet in depth, are commonly used to procure the alluvial waters. The waters are potable and safe in rural districts where the wells are sufficiently removed from outhouses or stables, but in towns the chances are great for pollution by the penetration of sewage into the unprotected gravels, and in such situations the shallower alluvial waters should be avoided.

The moraines of this county are low and inconspicuous, though their somewhat irregular surfaces stand in contrast with the very

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level aspect of the surrounding till plains. One belt of morainal drift extends from Greentown northwest into Miami and Cass counties, and Russiaville lies on another small isolated patch.

In the gravelly portions of the morainal drift the ground waters are abundant and may be obtained by dug, driven, or drilled wells. The gravel or sand beds between beds of till furnish the best waters, and the relatively impervious till is effective in keeping out objectionable drainage from the surface.

From its wide surface distribution (Pl. I) the till must be depended upon to furnish the domestic supplies of water throughout most of the county, and the usual method of obtaining water from it is by means of loosely curbed dug wells. The water thus obtained may, under exceptional conditions, be unfailing and pure; but many such wells fail in dry seasons and all are to some extent subject to the dangers of pollution either from the well mouth or from seepage through the ground. If dug wells are to be used, great caution should be exercised to locate them at as great a distance as possible from cesspools or other sources of contamination.

CONSOLIDATED MATERIALS.

The surface deposits of all of Howard County are immediately underlain by limestones. In the eastern portion the "Niagara" limestone is the uppermost formation. At Kokomo, where the rocks outcrop at the surface, the beds are of the Kokomo limestone ("water lime"), next younger than the Niagara. At Russiaville and in the extreme southwest portion of the county the Devonian limestones underlie the drift. The approximate distribution of these formations is shown in Plate III. The various limestone formations have gained the reputation among drillers of being sure water-bearing beds. A great many borings throughout the county have entered limestone, and almost without exception the wells have obtained satisfactory supplies of water.

Chemical analyses (p. 157) seem to show no great difference in composition between the waters from the limestone and those from gravel.

ARTESIAN AREAS.

Scattered throughout the county there are eight areas in which flowing wells occur. These are all in the lowlands, usually along the valleys of the larger streams. The outlines of the areas, as shown in Plate IV, are made to include the districts where flows are at present known. The boundaries are necessarily only approximate. The lack of an accurate topographic base map is one of the causes that have made it difficult, in the short time spent in each portion of the county, to map the flowing-well areas in detail and accurately.

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There is an area along the lowlands of Wild Cat and Kokomo creeks, near Kokomo (Pl. IV, No. 44), in which the limestone waters are under artesian pressure. The head of the waters is only a few feet above the level of the creeks, but at favorable spots flowing waters have been obtained. The best known of these areas is at the city park. The rock here lies only 18 feet below the surface, though the flowing wells, three in number, range from 49 to 106 feet in depth. The record of the strongest of the wells is No. 9 in the table on page 156. The wells at the city waterworks, farther upstream, are also reported to flow when not pumped. As they are all in use it was impossible to obtain the amount of flow or the head. On the property of Thomas J. Dye, 2½ miles south of Kokomo, gas borings have encountered flowing waters in the limestone at a depth of about 150 feet, one well in the lowlands of Kokomo Creek being estimated to flow 15 gallons per minute (No. 17, p. 156). There is reason to believe that other wells near the level of the creeks would give artesian flows.

Rock wells along Little Wild Cat Creek, near West Middleton, have obtained flowing waters from the limestone. (Pl. IV, No. 45.) The waters along this valley are under just enough pressure to rise to the surface, and the flows are small. Farther from the stream the waters in rock wells rise somewhat above the level of the creek but do not flow.

The west edge of Russiaville borders on West Honey Creek, in the valley of which there are flowing wells. (Pl. IV, No. 46.) Artesian waters are found in both the first and second gravels but none in rock. The deepest of these wells penetrated 35 feet of white sand and 62 feet of blue till to gravel at 97 feet and was cased only through the sand to the till.

A well one-half mile west of Fairfield (Pl. IV, No. 47) is reported[a] to have obtained a flow of 5,000 barrels per day from the limestone at a depth of 110 feet. The water rises 6 feet above the surface, which at this point is 25 feet lower than at the Fairfield railroad station.

About 1 mile west of Fairfield a small branch of Little Wild Cat Creek has a shallow valley in which there are two flowing wells (Pl. IV, No. 48), both of which are abandoned gas wells, the waters coming from the limestone. It is highly probable that rock wells in the valley bottom between this area and the flowing wells near West Middleton would also obtain flows.

In the valleys of Wildcat and Prairie creeks above Greentown there are at least three flowing wells, the flowing waters coming from the "Niagara" limestone, which here lies 50 to 75 feet below the surface. One well has a temperature of 51° F. and flows about 20 gallons per minute. There is reason to believe that wells which penetrate deep

[a] Leverett, Frank, Wells of northern Indiana: Water-Supply Paper U. S. Geol. Survey No. 21, 1899.

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into the limestone are likely to obtain flows anywhere in this county along the valley of Wild Cat Creek.

Area 13 (Pl. IV), which lies along a branch of Deer Creek, and which has been described in part as in Cass County (p. 90), contains three flowing wells in Howard County. One was drilled for gas and the other two for water. The gas well and the deeper of the water wells obtained the artesian flows from limestone. The shallower well secured a flow in gravel at a depth of 65 feet. The records of these wells are Nos. 14, 15, and 16 in the table on page 156.

Area 10, described in part on page 81, extends across the county line from Carroll into Howard County, where it contains one flowing well. This well (No. 1, p. 156) is about 35 feet above the level of Wild Cat Creek. The water is obtained within 6 inches below the top of the limestone, which was struck at a depth of 103½ feet. The materials passed through by this boring were as follows:

Log of well on farm of Richard Fisher, 1½ miles east of Burlington.

	Feet.
Gravel	9
Blue clay	30
Hardpan	50
Red clay	14½
Limestone	½
	104

CITY AND VILLAGE SUPPLIES.

Kokomo.—The Kokomo public waterworks are owned and operated by the American Water Works and Guarantee Company of Pittsburg, Pa., and the pumping station is situated at the east edge of the city near Wild Cat Creek. The water is drawn from 13 drilled wells scattered for over a mile along the creek bottom lands, and all enter the limestone, which here lies 15 to 30 feet below the surface. Some of the wells, which are 6, 8, and 10 inches in diameter, and range from 160 to 500 feet in depth, are said to flow at the surface when not pumped. At present they are all connected, and are drained by syphon into a large cistern at the pumping station. The water is pumped from this well to the mains, and direct pressure from the pumps is maintained. There are 30 miles of mains, 4 to 12 inches in diameter, and 2,500 taps. About 75 per cent of the people use this water, and require an average of 2,000,000 gallons per day.

When the pressure in the mains is increased for fire protection, a red sediment which accumulates in the mains is loosened and gives the water an objectionable reddish color. Proper flushing of the mains would do much to remedy this evil. The supply is otherwise very good and the danger of pollution is slight.

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Many private wells are still in use in Kokomo, and these usually obtain water in gravel just above the limestone, or in the limestone itself. The surface deposits vary in depth from 40 to 50 feet at the north edge of the city to only a few feet near the river. The most common type of well is the drilled well, which is sunk to a depth of about 75 feet and finds water in the limestone. The record of an old gas boring gives the following section:[a]

Log of gas boring at Kokomo.

	Feet.
Drift	61
Waterlime and Niagara	359
Hudson River limestone and shale	265
Utica shale	251
Trenton limestone	22
	958

Greentown.—The public supply of Greentown is owned by Delon & Davis, a private company. The water is taken from a single 4-inch drilled well, 95 feet deep, which penetrated 17 feet into limestone. The water rises within about 25 feet of the surface, and the head varies only 3 feet from this level in the driest seasons. A gasoline engine is used to pump the water to a tank 65 feet high, which holds 10,000 gallons and from which it is distributed by gravity. There is about 1 mile of mains, and 95 taps supply one-fourth of the population. The amount pumped varies from 5,000 gallons a day in winter to 20,000 a day in the dry seasons. The water is good and affords a very satisfactory supply.

The private wells in this town are dug, driven, or drilled and are from 20 to 150 feet in depth. Gravel beds are encountered at about 25, 45, and 95 feet, and these waters are much used. The overlying till beds afford to the deeper gravels a good protection from contamination, and the limestone waters are especially safe and abundant. The shallow dug wells are much more dangerous and should be abandoned.

Russiaville.—The water wells of Russiaville are mostly drilled or driven, but a few dug wells are still used. Most of the wells are shallow and obtain water in sand or gravel beds at depths of 15 to 40 feet. In parts of the town the surface deposits are very sandy, and water is difficult to obtain.

Other communities.—The following table contains a list of other villages, with particulars as to their water supply:

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 249.

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Village supplies in Howard County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Cassville	66	Wells, dug and drilled	10	110	25	100	.....	Gravel, sand, and limestone.
Center	279	Wells, drilled, driven, and dug.	15	135	60	70–100	.....	Limestone and gravel.
Fairfield	.....	Wells, dug and drilled	12	110	100	60	10	Gravel and limestone.
Hemlock	104	.....do.....	18	115	20	85	10	Do.
Jerome	.....	Wells, dug, driven, and drilled.	20	125	.....	70–100	.....	Clay, gravel, and limestone.
Kappa	24	Wells, drilled and dug	18	150	115	90	10	Gravel and limestone.
New London	177	Wells, dug and driven	18	40	30	.....	.....	Gravel.
Phlox	51	Wells, drilled and dug	15	80	60	60	10	Gravel and limestone.
Plevna	57	.....do.....	18	120	100	65	.....	Do.
Ridgeway	18	.....do.....	20	150	100	80	20	Do.
Sycamore	271	.....do.....	25	125	100	60	8	Do.
Vermont	.....	.....do.....	25	142	30	142	.....	Do.
West Liberty	60	.....do.....	15	85	60	50–80	12	Sand and limestone.
West Middleton.	202	.....do.....	15	108	20	100	.....	Gravel and limestone.

TYPICAL WELLS AND ANALYSES.

In the following tables are given detailed information as to typical wells in Howard County, and analyses of their waters. In the last column of each table the numbers refer to identical wells in the other table.

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Records of typical wells in Howard County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Feet.*	*Gallons.*	°*F.*	
1	Richard Fisher	1½ miles E. of Burlington	104	Drilled	2		+17½	Limestone	103	6	53	
2	J. P. Rauchert	Cassville	110	do	4	110	+ 8	do			52½	
3	Simpson estate	Center	135	do	4			do				1
4	Jacob Jessepp	2 miles E. of Center	280	do	4			do	80			
5	Everett Scott	Greentown	124	do	4		−22	do	118			
6	Delon & Davis	do	95	do	4	95	−26	do	78			
7	Samuel Ingalls	Hemlock	109	do	4			do	90			2
8	Public supply	Kokomo	160	do	6		+	do	26			4, 5
9	City park	do	106	do	6	50	+	do	18	10		3, 6
10	Kokomo Rubber Works	do	125	do	6		− 8	do	11			
11	Henry C. Wright Hoop Co	do	114	do	4		− 6	do	49			
12	Pittsburg Plate Glass Co	do	350	do	5½			do	22			
13	J. M. Leach	do	250	do	10	75	−14	do	16			
14	Jane D. Toubey	5½ miles NE. of Kokomo	65	Driven	2	65	+ 6	Gravel				
15	A. J. Hutson	do	900	Drilled	8		+12	Limestone				
16	Mary T. Smith	5 miles NE. of Kokomo	117	do	3½	117	+ 5	do	70			
17	Thomas J. Dye	2½ miles S. of Kokomo	1,000	do		150	+	do	20	15		
18	F. M. Baker	New London	30	Dug				Gravel				9
19	C. W. Hollingsworth	Russiaville	40	Drilled	2	40	−15	do				10
20	M. B. Jordan	do	97	Driven	2½	97	+ 5	do		5	52	11
21	Thomas E. Pickett	Sycamore	110	Drilled	4	110		Limestone	70			
22	Schoolhouse	Vermont	156	do	4			do	142			
23	Thomas E. Pickett	1 mile S. of West Liberty		do			+	do	140			
24	Marion Curless	½ mile SE. of West Liberty		do	8		+ 3	do			51	12
25	Public well	West Middleton	95	do	4	95	− 8	Gravel	95			13

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Mineral analyses of waters in Howard County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Simpson estate	Center	Drilled well, 35 ft. by 4 in.	H. E. Barnard.	Nov., 1907.	Limestone		1.0		46	30			0.0	288	0.0	5.0	0.10	0.001	2	532	3
2	Samuel Ingalls	Hemlock	Drilled well, 109 ft. by 4 in.	do	do	do		2.0		61	27			.0	360	27	4.0	.00	.000	5	462	7
3	City park	Kokomo	Drilled well,[a] 106 ft. by 6 in.	do	Oct., 1907.	do		.10		60	32			.0	310		37	.00	.32	9		9
4	City supply	do	Drilled wells, 160 ft. by 6 in.	J. H. Brewster.	Apr., 1907.	do		1.0		94	31			168		75(?)	7.5				317	8
5	Do	do	Drilled well, 500 ft. by 10 in.	L. S. & M. S. R. R.	Feb., 1904.			1.9		87	32	12		176		67	9.7					8
6	City park	do	Drilled well, 106 ft. by 6 in.	Chase Palmer.	Aug., 1907.	Limestone	20	.4		63	32	25		.0	357	12	32	.0			372	9
7	Kneer Paper Co.	do	Drilled well, 450 ft. by 8 in.	L. S. & M. S. R. R.	Aug., 1903.			2.3		122	45	34		223		114	52	1.4				
8		do	Wild Cat Creek[b]	do	Sept., 1904.					65	23	8.7		145		23	6.0	4.4				
9	F. M. Baker	New London	Open well, 30 ft.	H. E. Barnard.	Nov., 1907.	Gravel		.10		71	36			.0	272	240	41	4.0	.00	8	636	18
10	C. M. Hollingsworth.	Russiaville	Drilled well, 40 ft. by 2 in.	do	do	do		.60		29	29			.0	255	81	10	.05	.00	1	378	19
11	M. B. Jordan	do	Driven well, 97 ft. by 2½ in.	do	do	do		.80		70	31			.0	298	.0	98	.70	.001	12	360	20
12	Marion Curless	½ mile SE. of West Liberty.	Drilled—old gas well.	do	do	Limestone		.80		83	27			.0	304	58	7.0	.05	.00	2	466	24
13	Public well	West Middleton.	Drilled well, 95 ft. by 4 in.	do	do	Gravel		.01		93	33			.0	326	.0	13	.100	.001	10	400	25

[a] Water at 50 feet.

[b] Normal stage.

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KOSCIUSKO COUNTY.

SURFACE FEATURES AND DRAINAGE.

Kosciusko County lies in the eastern tier of counties in the area covered by this report and in the second tier from the north edge of the State. It is the largest county in this region, having an area of 521 square miles. The 1900 census showed a population of 29,109, or an average of about 56 persons to the square mile.

The surface of this county is high, and the drainage is divided between the tributaries of Tippecanoe, Eel, Elkhart, and Yellow rivers, although within the county none of these streams is large. The moraines of the south and east parts are prominent and give considerable relief to the surface, but the northwest quarter of the county is flat and poorly drained.

The surface deposits are of extraordinary thickness, so that little is known about the shape of the rock surface. The present topography is entirely due to the form of the glacial deposits and to the subsequent slight erosion of their surface. Only one boring in the county has penetrated to rock, which lies at a depth of 245 feet at Warsaw. In Noble County, to the east, depths of 375 and 485 feet have been reached before rock was encountered.

Tippecanoe River receives most of the drainage from the county, including the overflow from a large number of lakes. All its tributaries are small, and the Tippecanoe itself is not a large stream in this region of its headwaters. Eel River crosses the southeast corner; but its valley here is not large and its tributaries all of which are unimportant, reach back into only the southern tier of townships.

Turkey Creek, a branch of Elkhart River, heads south into the area near Wawasee Lake and drains most of Van Buren and Turkey Creek townships. Scott and Jefferson townships had naturally very poor drainage, and much of the land was formerly useless for cultivation on account of its marshy character. Artificial drainage ditches have now been constructed to Yellow River, and much of the land has been reclaimed.

Kosciusko County has an exceptionally large number of lakes and ponds—more than any other county in this region. These range in size from Wawasee, or Turkey Lake, which has an area of about 6 square miles and is the largest lake in the State, to small ponds only a fraction of a square mile in area. All the lakes occupy depressions in the morainic material, and many of them have been partly filled by silt and by vegetable growths and are marshy.

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GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

There are no important areas of valley alluvium in the county. Narrow flood plains occur along Tippecanoe and Eel rivers, and occasionally small benches of alluvium are found locally in the smaller valleys; but they are nowhere of sufficient extent to be important sources of water supply.

The outwash plain northwest of Warsaw has considerable gravel and sand mixed with clayey materials and is alluvial in its nature. At Leesburg and at Menoquet the outwash deposits are thick enough to furnish important water supplies to driven wells of shallow depth. Farther northwest the outwash becomes thinner and most wells pass through it into the underlying till for their water.

A great morainic belt covers much of this county (Pl. I), with its surface diversified by rolling hills and hummocks and many of the intervening depressions occupied by lakes. The morainic belt is broad, and although it forms a sharp ridge in few places it reaches heights of about 100 feet above the bordering plains. Water for wells of moderate depth is particularly abundant in the moraines. Most of the wells are driven and find plenty of water at 30 feet or less, but in the more clayey portions wells of greater depth are locally necessary. In the lowlands, near streams or lakes, the gravel beds in places contain water under sufficient head to flow at the surface; but these conditions are strictly local. The water in such cases is derived from the uplands at no great distance from the wells.

As shown in Plate I, the till covers a relatively small portion of the surface of the county. Its importance is greater, however, than its surface distribution would indicate, for throughout the entire county the other surface deposits are underlain by a layer of till which will probably average 200 feet in thickness. Its character is the same as in other parts of this area. In the moraines and the area of heaviest outwash water is commonly obtained above the till; but in those places where the till comes to the surface or where the outwash is thin deep driven or drilled wells penetrate into the till to some gravel or sand bed. Such open beds bear abundant waters which are hard but uncontaminated.

CONSOLIDATED MATERIALS.

As a result of the very heavy mantle of glacial beds, the underlying rocks are nowhere at the surface in Kosciusko County, and only one well was found which had penetrated rock. No attempt has been made to map the distribution of the rock formations; but a well at Warsaw entered limestone, which is presumably of "Niagara" age, and it may be that later formations overlie the "Niagara" at the north edge of the county. This well, which was drilled for oil or gas,

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may be the only well at Warsaw that receives its water supply from the rock. The water is under artesian pressure and discharges a small stream 4 feet above the surface. (No. 17, p. 164.) An analysis of this water is No. 18 in the table on page 165.

ARTESIAN AREAS.

There are about half a dozen flowing wells in Warsaw (Pl. IV, No. 50), all but one of which obtain the water from gravel beds in the moraine upon which the town is situated. The depth to the flowing water differs in different parts of the town, and the conclusion is that different beds of gravel are drawn upon and that the beds are irregular in shape and distribution. At the waterworks plant a number of small flows were obtained from a depth of 135 feet. At the chair factory of A. Wilder & Co. a well 18 feet deep struck water that rises to the surface. Other flowing wells have been obtained at depths of 78 and 85 feet, but they are in the lower parts of town, and the head is sufficient to give flows only in the lowlands. A complete analysis of one of these waters is No. 17 in the table on page 165.

A single well in Warsaw (No. 17, p. 164) is said to obtain water from a rock bed, which is probably of "Niagara" age. This well is reported to be cased to a depth of 400 feet, so that the water, which flows as a small stream 2 feet above the surface, must come from below this depth if the casing is still intact. An analysis of the water is No. 18 in the table on page 165. The very remarkable similarity between this water and that from a shallow well in the drift (No. 17, p. 164) indicates strongly that the water from both wells is from the same depth or at least that both are drift waters.

Area 51 (Pl. IV) includes the village of Kalorama, a summer resort on the northeast shore of Tippecanoe Lake, which lies in a depression in the great interlobate moraine. The conditions are favorable for artesian wells, and a number of these have been obtained and are now flowing. All are driven wells, sunk through pebbly clay into gravel at 60 to 75 feet below the surface. The source of the flowing water is in the moraine to the north, and the intake of the water is probably not more than a mile, at most, from the point of emergence. Flows are to be expected only in the lowlands.

A single flowing well is reported from northwest of Wauwas Lake, on the property of the Indiana Portland Cement Company. (Pl. IV, No. 52.) This is said to be a driven well and to flow in a 2-inch stream. The well is at the foot of a moraine ridge, and the waters are probably supplied to the well by a gravel bed which outcrops somewhere in the higher moraine to the east.

A flowing well is reported from the farm of Samuel Kile, three-fourths of a mile north of Wooster. (Pl. IV, No. 53.) It occurs in the lowlands and the water is obtained in gravel. The well is said to flow in a small stream.

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There is a single flowing well between Claypool and Burket, near a small creek which flows into Palestine Lake. (Pl. IV, No. 54.) The well extends 60 feet into gravel, and the water rises 3 feet above ground and discharges several gallons per minute. The head is doubtless from the moraine ridge to the southeast.

On the property of Lucinda Hazen, 2 miles northeast of Etna Green, a flowing well has been obtained on low ground. (Pl. IV, No. 55.) The well is driven 82 feet to a gravel bed, and at 3 feet above the surface flows in a 1-inch stream. Other flows may probably be obtained in the neighborhood on equally low ground.

CITY AND VILLAGE SUPPLIES.

Warsaw.—The public supply at Warsaw is owned and operated by the Winona Water and Light Company and the water is drawn from Center Lake, a small body of water at the edge of the town. Sanitary analyses have so far shown this water to be free from colon bacilli, but it is heavily charged with organic matter of other kinds. A marsh at the edge of town which has been used as a dumping ground for all sorts of refuse drains into this lake. In flood seasons Tippecanoe River, into which the sewage from Warsaw drains, backs up through a canal into Center Lake. At times the water has a decided smell and taste of decayed organic matter. By the installation of a good filtration system much of the objectionable matter could be removed and the supply could be made a very desirable one.

At one time the water company drilled 14 wells, which obtained flowing waters in gravel at a depth of about 135 feet. These wells were all "in sympathy" with one another and with other flowing wells in town. The supply from them was insufficient for the demands of the public, and they have been abandoned in favor of the lake water.

The water for city consumption is pumped to a standpipe 125 feet high, from which it is distributed by gravity. There are 7 to 8 miles of mains, 10, 8, 6, and 4 inches in diameter, and 800 taps are in use. About two-thirds of the people use the city water supply, and 1,000,000 gallons a day are pumped.

The people of Warsaw realize that the public water supply is unsafe, and almost every family owns a well for drinking water. These are driven or dug and range from 12 to 150 feet in depth. All terminate in gravel or sand, for the limestone here lies about 250 feet below the surface. In favored localities the wells flow, and even on higher ground the waters commonly rise within a few feet of the surface. The following materials were penetrated by a deep boring for oil in this town:[a]

[a] Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., p. 265.

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Log of boring for oil at Warsaw.

	Feet.
Drift	248
Niagara limestone	652
Hudson River and Utica	478
Trenton limestone	77
	1,464

Syracuse.—Syracuse is situated on the west shore of a lake of the same name, and lies partly on the flat and partly on a well-developed morainic ridge. The public waterworks are owned by the city, and the water is taken from the lake and carried through an open mill race for about a mile through the town. Along the race there are houses, barns, and cesspools, and the chances for pollution are abundant. The water is pumped by water power developed at the end of the race and is forced to a standpipe on the hill. The standpipe has a capacity of 32,000 gallons. The water is distributed by gravity and is used by about 20 per cent of the people. From 5,000 to 30,000 gallons per day are used.

About four-fifths of the people of Syracuse rely upon private wells for their water supply, and most of these wells are driven. On the hill the wells range in depth from 35 to 130 feet, while on lower ground the deepest wells are only 35 and the shallowest only 12 feet deep. Gravel was found by all wells, and the water is everywhere abundant.

Milford.—The town of Milford is situated on an outwash gravel plain in the north-central part of the county. The town owns its own water system, which has been in operation since 1892. The water is taken from four drilled wells, each 40 feet deep, situated near the grist mill by which the pumping is done. The water is forced to an 83,000-gallon standpipe, 110 feet high, and is distributed by gravity. There are 2½ miles of mains, and 71 taps are in use, supplying 33 per cent of the population. An average of about 20,000 gallons of water a day is pumped.

The private supply of Milford is almost all from driven wells, which range in depth from 40 to 60 feet. The material penetrated is all gravel and sand, and the water is very abundant and rises within 6 or 8 feet of the surface. Milford has no sewage system, and all the drainage from dug privy vaults, kitchen slops, stables, and other sources can readily enter the loose soil and become a part of the underground water supply. For this reason it is advisable to drive the wells deeply into the gravel and to draw water only from the lower and purer beds.

Pierceton.—The town of Pierceton installed its own water works in 1897, and a single drilled well furnishes the entire supply. The well is 8 inches in diameter and 210 feet deep, and the water is supplied by a gravel bed 10 feet above the bottom of the well, and rises within

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50 feet of the well mouth. An analysis is No. 8 in the table on page 165. A deep-well pump lifts the water to a wooden tank of 15,000 gallons capacity, and from the tank it is pumped by direct pressure into the mains, which are 6 and 4 inches in diameter and between 1½ and 2 miles long. About 200 taps are supplied and 20,000 gallons per day are needed to supply 50 per cent of the people. The water is of fine quality, and the supply a very satisfactory one. There has been some complaint because the wooden reservoir becomes slimy at times, but reasonable care could prevent this.

Mentone.—In Mentone, which has no public supply, the wells are all privately owned, and are driven, dug, or bored. The town lies on a till plain, and the wells all pass through this material into gravel, which is generally encountered at depths of 30 and 80 feet. Some of the waters from dug and bored wells are evidently bad, and the chances of contamination in such wells are many times greater than in the wells from the deeper beds. An analysis of water from a depth of 90 feet is No. 6 in the table on page 165.

Other communities.—A tabulated list of other villages, with the conditions of their water supply, is given below:

Other village supplies in Kosciusko County.

Town.	Population (1900).	Source.	Depth of wells.			Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.		
			Feet.	*Feet.*	*Feet.*	*Feet.*	
Atwood	278	Wells, drilled and driven	20	60	45	−30	Gravel.
Burket	286	do	10	80	15	.....	Do.
Claypool	399	Wells, dug and drilled	10	110	70	−20 to −50	Gravel and sand.
Clunette	91	Wells, driven	20	35	30	−28	Sand.
Etna Green	420	Wells, driven and drilled	14	100	25	−12	Gravel
Gravelton	28	Wells, driven and dug	20	100	90	.....	Do.
Hastings	16	Wells, driven	35	100	50	.....	Do.
Kalorama	.....	do	30	70	60	+6 to −5	Do.
Kinzie	67	Wells, dug and driven	20	65	25	−20	Do.
Leesburg	390	Wells, driven	15	30	20	−15	Do.
Menoquet	.....	do	14	60	20	−15	Do.
Milford Junction.	.....	Wells, driven and drilled	16	44	18	−16	Do.
North Webster	300	Wells, driven	18	30	22	− 8	Do.
Oswego	61	do	15	125	20	−15	Do.
Packerton	213	Wells, driven, drilled, and dug.	20	120	80	.....	Do.
Palestine	126	Wells, driven and drilled	30	65	30	−30	Do.
Sevastopol	105	Wells, driven and dug	15	100	60	.....	Do.
Sidney	300	do	20	140	50	−15	Do.
Vawters Park	25	Wells, driven	12	60	25	.....	Do.
Wawasee	22	do	20	40	25	.....	Do.
Winona Lake	156	Wells, drilled and driven	20	100	95	+4 to −10	Do.
Wooster	72	Wells, driven	20	100	26	.....	Do.

TYPICAL WELLS AND ANALYSES.

The following tables give detailed information regarding typical wells in Kosciusko County and analyses of their waters. The last column of each table contains numbers referring to identical wells in the other table.

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Records of typical wells in Kosciusko County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*In.*	*Feet.*	*Feet.*		*Galls.*	*° F*	
1	Public well	Burket	18	Driven	1¼	16	− 10	Gravel			1
2	do	Claypool	68	Drilled	2	65	− 30	do			2
3	do	Etna Green	95	Driven	1¼	90	− 12	do			4
4	Peter Newcomb	do	55	do	2	50	− 40	do			3
5	Lucinda Hazen	2 miles northeast of Etna Green.	82	do	1¼	82	+ 3	do			
6	Public well at bank	Leesburg	18	do	1¼	18	− 18	do			5
7	Public supply	Milford	40	Drilled	4		− 8	do			7
8	do	Pierceton	210	do	8	200	− 50	do			8
9	Mrs. A. Personet	Sevastopol	99	do	1¼	95	− 30	do			9
10	J. L. Warvel	Sidney	45	Driven	2	45	− 15	do			10
11	S. N. Hawley	do	143	do	2	140	−100	do			11
12	Public well	Silver Lake	26	Dug		26		do			12
13	Public well at post-office.	Syracuse	42	Driven	2	42		do			13
14	Winona Light and Water Co.	Warsaw	150	Drilled	8	135	+ 2½	do			
15	A. Wilder & Co	do	18	Driven	1	18	+ 0	do			
16	Henry Shane	do	78	Drilled	2	78	+ 2	Sand	1	52	17
17	Mrs. A. Oldfather	do	+400	do	8		+ 4	Gravel	1½	53	15
18	Winona Lake assembly.	Winona Lake	95	do	3	85	+ 1	do			
19	do	Power plant, Winona Lake.	96	do		96	+ 4	do			14
20	do	Winona Lake	63	do	2	63	+ 8	do			

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Mineral analyses of waters in Kosciusko County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Public well	Burket	Driven well, 18 ft. by 1¼ in.	H. E. Barnard	Sept.,1907	Gravel	....	0.60	....	118	27	....	....	0.0	240	41	55	2.50	0.002	2	566	1
2	do	Claypool	Drilled well, 68 ft. by 2 in.	do	do	do	....	1.2	....	108	28	....	....	.0	293	32	9.0	.10	.....	2	370	2
3	Peter Newcomb	Etna Green	Driven well, 55 ft. by 2 in.	do	do	do	....	1.60	....	94	26	....	....	.0	241	64	26	4.0	.001	9	400	4
4	Public well	do	Driven well, 95 ft. by 1¼ in.	do	do	do	....	1.6	....	83	27	....	....	.0	302	10.7	1	.20	.001	42	342	3
5	do	Leesburg	Driven well, 18 ft. by 1¼ in.	do	1907	do	....	.01	....	112	26	....	....	.0	304	99	31	6.0	.00	4	532	6
6	do	Mentone	Well, 90 ft. by 2 in	do	do	do	....	.20	....	64	20	....	....	.0	243	64	11	.40	.00	4	534	....
7	Waterworks wells	Milford	Drilled wells, 40 ft. by 4 in.	do	do	Gravel	....	.01	....	68	23	....	....	.0	224	160	15	2.0	.00	2	312	7
8	do	Pierceton	Drilled well, 210 ft. by 8 in.	do	Sept.,1907	do	....	.15	....	53	30	....	....	.0	294	1.2	1	.40	.001	19	344	8
9	Mrs. A. Personet	Sevastopol	Drilled well, 99 ft. by 1¼ in.	do	do	do	....	.10	....	106	26	....	....	.0	294	7	9	.00	.00	4	322	9
10	J. L. Warvel	Sidney	Driven well, 45 ft. by 2 in.	do	do	do	....	1.2	....	....	....	....	....	....	....	.0	34	.05	.001	42	464	10
11	S. N. Hawley	do	Driven well,143 ft. by 2 in.	do	do	do	....	1.4	....	66	30	....	....	.0	303	93	1.0	0.3	.001	13	416	11
12	Public well	Silverlake	Open well, 26 ft.	do	do	do	....	.04	....	138	36	....	....	.0	378	52	76	8	.001	9	696	12
13	do	Syracuse	Driven well, 42 ft. by 2 in.	do	do	do	....	.60	....	80	35	....	....	.0	342	140	17	.10	.00	4	404	13
14	Winona Water and Light Co.	Winona Lake.	Drilled wells, 96 ft.	do	do	do	....	.3	....	87	25	....	....	.0	292	9	2	.30	.001	9	282	19
15	Winona Lake Assembly.	Assembly grounds.	Grotto Spring	A. B. Prescott	....	....	13	.70	0.48	84	24	4.3	0.45	.....	323	48	3.9	.44	.....	....	339	....
16	.....	Warsaw	Center Lake	Pennsylvania R. R.	....	....	9.9	4.1		88	8.1	9.5		109	....	66	14	....	.....	....	321	....
17	Henry Shane	do	Drilled well, 78 ft. by 2 in.	R. B. Dole	Sept.,1907	Sand	27	1.06	....	62	26	25.		.0	339	8.6	.2	1.2	.....	....	304	16
18	Mrs. Anna Oldfather.	do	Drilled well, 400 ft.	do	do	Gravel	27	1.3	....	62	26	23.		.0	345	4.8	.2	1.5	.....	....	305	17

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MADISON COUNTY.

SURFACE FEATURES AND DRAINAGE.

Madison County, which lies on the east edge of this area and in the second tier of counties from the south edge, is rectangular in outline and about twice as long as broad. Anderson, the county seat, is 32 miles northeast of Indianapolis. The county has an area of about 460 square miles, and had in 1900 a population of 70,470, or an average of 153 to the square mile. This population is due in part to the fertility of the farm lands, but is to a greater extent the result of the finds of natural gas in this and adjoining counties. At the present time, however, the supply of natural gas has decreased noticeably, many wells have been abandoned, and many factories whose existence depended on this cheap fuel have shut down.

The maximum relief of this county is a little more than 100 feet, but a large portion of its surface lies between 850 and 900 feet above sea level (Pl. I). The surface is a nearly level plain, interrupted only by the valleys of the larger streams.

The entire surface drainage of the county is received by White River and its tributaries. This river, which crosses the county from east to west somewhat south of the center, has a valley in most places much less than 90 feet deep, and commonly not more than one-half mile wide. Fall Creek, the largest tributary, crosses the south edge of the county. Near Emporia its valley is about 40 feet below the till plain, and becomes deeper westward. Pipe Creek, the most important tributary from the north, flows from the northeast corner to join White River a mile below Perkinsville. Each of these three large streams has a number of less important tributaries, but most of the valleys are mere grooves in the plain, and the uplands are flat and uneroded.

As moraines are lacking in the county, there are no natural lakes. The level plains offer no undrained depressions to form lake basins, and there is no evidence that lakes have ever existed here.

The only noteworthy area in which marshes occur is in the northwest corner, between the headwaters of Pipe Creek and Mississinewa River. Here a very flat area was formerly marshy, but by means of artificial surface ditches and by tiling the wet fields much of this land has been reclaimed.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Important alluvial beds are found only along the bottoms of White River and Fall and Pipe creeks (Pl. I). These range in width from a few feet to about one-half mile, and their width along a single valley

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varies within short distances. Wells that penetrate the alluvium almost invariably reach abundant water at no great depth.

Pebbly clay or till occupies almost all of the surface except the narrow belts of valley alluvium, and is continuous below most of the alluvial beds (Pl. I). The thickness of the till throughout the county is shown in Plate II. At a few points in the deep valleys the bed rock outcrops and the till is absent, but at other places it is very thick. North of Halford is a narrow belt that is doubtless a part of the valley of a preglacial stream, in which the till is from 300 to 500 feet thick (Pl. II). It is possible that this buried valley extends to the northeast and connects with the valley that crosses Grant County, though the course it follows is not clear. Throughout the county as a whole the thickness of the till averages about 100 feet.

In most of that part of the county which lies south of Alexandria the drift is so deep that the ordinary wells do not go through it but obtain supplies of water from the drift itself. Many loosely curbed dug wells are in use, and some of them fail to reach gravel beds, but are supplied by slow seepage from the pebbly clay. Drilled wells are now becoming more popular, and experience has shown that few of these fail to find a water-bearing gravel bed somewhere above the limestone. The drift waters are all very hard, and, though good for household and farm purposes if not polluted, they are poor for steaming.

CONSOLIDATED MATERIALS.

The "Niagara" limestone, the youngest rock formation in this county, is everywhere the first bed rock found beneath the till. It outcrops in the valley of Fall Creek near Pendleton and in the White River valley near Anderson, but is elsewhere covered by glacial deposits of various thickness. The discovery of natural gas in this region has brought about the drilling of many deep wells, and by compiling the records of these it has been possible to determine approximately the depth to rock throughout the county (Pl. II). The "Niagara" limestone has proved to be a reliable source of supply for drilled wells. This fact became generally known when it was found that all gas borings had to be cased through the "Niagara" to keep the "Niagara" waters out of the lower part of the well. The waters are under artesian pressure and will flow at the surface in many lowland areas. Large numbers of abandoned gas wells are used for their water supply, and many rock wells have been drilled for the purpose of obtaining water, especially in those localities where the surface deposits are of moderate thickness. The waters are hard, but the overlying till protects them from contamination and the sanitary condition is usually excellent.

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ARTESIAN AREAS.

Flowing wells have been obtained in an area along the bottom of Pipe Creek valley extending from below Frankton above Alexandria and including the lower ends of some of the larger tributary valleys. (Pl. IV, No. 56.) All these wells are on very low ground near the stream, and almost all are old gas wells, the water coming from the "Niagara" limestone. The largest flow is from a well 2 miles northeast of Frankton, which yields about 90 gallons per minute, and most of the flows are much less. It seems probable that wells in the valley below Frankton, as far down as the mouth, would find flowing waters. Records of flowing wells in this area are Nos. 16 and 17 in the table on page 174.

Area 57 (Pl. IV) includes the valley of White River for some distance above and below Anderson. In this area are several flowing wells, all of which procure water from the "Niagara" limestone. The source of the waters may be from the southeast toward Richmond, for in this direction the limestone is higher than in Madison County and in the intervening area the drift covering is thick. It is probable, however, that the water supply of this limestone is at least in part from the overlying till, and the artesian head may be from the till rather than from distant outcrops of this formation. This area may possibly be continuous downstream with area 56, by way of the lower valley of Pipe Creek.

In area 58 (Pl. IV) the conditions are very similar to those already described for areas 56 and 57. It includes the valley of Fall Creek entirely across the county, and the valley of Lick Creek to a point above Ingalls. Almost every gas well in the valley bottom between Pendleton and Middleton in Henry County yields flowing water. As in areas 56 and 57, the waters are from the "Niagara" limestone and the head is from the southeast. Further drilling will be likely to extend this area westward, as the valley becomes lower in that direction, and flows may be found along Fall Creek in Hamilton County.

A single flowing well is reported from the farm of Mr. John Fisher, 2½ miles southeast of Pendleton, in the valley of a small stream. (Pl. IV, No. 59.) This well was bored for gas, and the limestone was entered 60 feet below the surface. The "Niagara" is here 203 feet thick, and the flowing water comes from it.

In area 60 (Pl. IV), comprising a low, flat portion of the till plain south of Markleville, in the southeast corner of the county, there are a dozen or more flowing wells, all from gas borings. The water comes from the "Niagara," and the surface in this area is low enough to permit the water to flow.

A number of flowing wells are reported from an area between Ingalls and Lapel. (Pl. IV, No. 61.) These differ from the flowing

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wells described above in that the water is obtained from gravel in the till and the rock is not penetrated. Some of the wells flow in good volume, which shows no signs of diminishing.

There are several flowing wells in the neighborhood of Lapel (Pl. IV, No. 62), the flows being obtained from the "Niagara" limestone. One is estimated to yield 48 gallons per minute and another (No. 21, p. 174), attached to a hydraulic ram, pumps sufficient water for a house and barn. The least depth at which flowing waters have been reached is 55 feet, at the north edge of Lapel. The limestone was here reached at 35 feet below the surface.

CITY AND VILLAGE SUPPLIES.

Anderson.—The city of Anderson owns its own water supply, and the water is taken from White River, which flows through the city. Although no sewage enters the river for 3 or 4 miles above the waterworks, large quantities of it enter the river at Muncie, about 20 miles above, as well as at Winchester and at half a dozen villages between. Daily bacteria counts are made by the local health officer, and the number ranges from 800 to 400,000 per cubic centimeter in the raw river water. The number increases greatly after a rain. Within recent years a system for the filtration of the water has been installed, and is now being operated very successfully. The water is pumped from the river into coagulating basins, and to it are added from 1½ to 2 grains of sulphate of alumina to each gallon of water. This acts as a coagulant. The water is then run by gravity into filter tanks. The filter consists of 4 feet of fine sand overlying 1 foot of gravel. From the filter beds the water is run into a clear tank holding 500,000 gallons, and from this it is pumped by direct pressure into the mains. There are now in use 32½ miles of mains from 20 to 4 inches in diameter, and 2,200 taps are supplied. About one-third of the people use the city water, and the average daily pump is 1,500,000 gallons. Bacterial counts of the filtered and unfiltered waters show that the present process removes 96 to 98½ per cent of the bacteria, and the appearance is changed from that of a very muddy and unpleasant to a clear and sparkling water.

Many privately owned wells are still in use at Anderson, and almost all the drinking water is obtained from them. The water wells are dug, driven, and drilled and range in depth from 18 to 350 feet. In the city the rock is commonly reached about 120 feet below the surface. Wells shallower than this get water from gravel beds, and these are the most common, while rock wells are few in number. There are good springs along the sides of the river valley. A deep gas boring at Anderson gave the following section:[a]

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 236.

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Log of gas well at Anderson.

	Feet.
Drift	114
Niagara limestone and shale	186
Clinton(?)	20
Hudson River and Utica	494
Trenton limestone	24
	838

Elwood.—The public supply of Elwood, owned by the Elwood Water Company, a private concern, is drawn from 14 drilled wells, located near the pumping station. Of these, 10 are 150 feet deep and 4 are 400 feet deep, all are 8 inches in diameter, and all obtain their water from the "Niagara" limestone. The water rises within 20 feet of the surface—that is, 40 feet above the limestone. The water is pumped directly from the wells into the mains.

There are two surface reservoirs which together hold 1,500,000 gallons for a reserve supply in case of fire, but otherwise these are not used. There are 14 miles of mains and 1,100 taps, and on an average 650,000 gallons per day are needed to supply about 40 per cent of the population. An analysis of this water is No. 16 in the table on page 175.

Most of the private wells in Elwood are dug, and range from 15 to 20 feet in depth. The water is found in clay or sand, but is too near the surface to be safe from pollution, especially where the wells are located among dwellings, barns, and other buildings. The water from the deeper wells or city supply is much safer. Some drilled wells have found abundant water in limestone at 60 to 150 feet below the surface, and this supply is highly recommended.

Alexandria.—The town of Alexandria owns a public supply obtained from seven drilled wells. Of these five were drilled for water and are located at the pumping station. They are 10 inches in diameter and 350 feet deep, all except the upper 15 or 20 feet being in the "Niagara" limestone. The chief water supply was reached at a depth of 110 feet. The pumps are also connected with two old gas borings, one 500 and the other 1,800 feet south of the pumping station. The water is pumped to a standpipe 100 feet high and holding 235,000 gallons, and is distributed by gravity. There are 10 miles of mains and 500 taps in use, and somewhat over 50 per cent of the people are supplied. About 300,000 gallons of water are used each day. Mineral analyses of the city water are Nos. 4 and 5 in the table on page 175.

Most of the private wells in Alexandria are drilled, and water from both the gravels and the underlying rock is used. Most of the wells that are 60 to 70 feet deep obtain an unfailing supply of water from the rock, although the head is said to be 25 feet lower than it was ten

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years ago. The geologic section at Alexandria, as shown by a gas boring, is as follows:[a]

Log of gas well at Alexandria.

	Feet.
Drift	20
Niagara limestone	261
Hudson River and Utica shale	611
Trenton limestone	5
	897

Frankton.—The Frankton public supply was installed in 1899 and is owned by the town. The water is drawn from a dug well 20 feet deep and 20 feet in diameter. This well is located 30 feet from Pipe Creek and only 10 feet above it, and in flood times the creek water can run into the top of the well. During even the normal stages of the creek the water is poor, though clear, and is used largely for sprinkling. There are 4 miles of mains and the water is used by about 40 per cent of the people. About 25,000 gallons per day are consumed.

Nearly every family in Frankton owns a well, most of the wells being dug and from 15 to 20 feet deep. In the south and east parts of the town are some drilled wells that go into limestone at a depth of about 130 feet. The shallow wells are in great danger of pollution by the penetration downward, from the surface and from dug cesspools, of sewage and organic matter of various sorts. Where it is possible the deeper drilled wells should be used, as they are much safer.

Summitville.—The Summitville water system, which is owned by the town and was installed in 1902, is supplied by a single drilled well 8 inches in diameter and 347½ feet deep. The well was drilled through the bottom of the "Niagara" limestone, which is here 100 feet below the surface. No reservoir is used, and the pressure is maintained directly from the pumps. There are 2½ miles of 8 and 4 inch mains and 130 taps, by which somewhat less than half the people are supplied. The well furnishes sufficient water for the ordinary city demand, but the pumping works are connected with a pond from which water can be drawn in case of fire.

In Summitville the private wells are dug, driven, or drilled, the dug wells 13 to 30 feet, and the driven wells 60 to 100 feet deep. The common depth to which wells are sunk is 60 feet, and gravel beds supply most of the water. Mineral analyses of wells of the dug type and of drilled wells in the limestone are Nos. 29, 30, and 31 in the table on page 176.

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 235.

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The geologic section at Summitville is given below, as determined by a gas-well boring.

Log of gas well at Summitville.[a]

	Feet.
Drift	100
Niagara limestone	236
Hudson River limestone and shale	300
Utica shale	292
Trenton limestone	50
	978

Pendleton.—Pendleton is on the banks of Fall Creek, the valley of which is here cut 50 feet below the till plain. The "Niagara" limestone outcrops along the creek above and below town, and the drift in the lowlands is nowhere more than 18 feet thick. All the wells are drilled into rock and range in depth from 28 to 140 feet, the common depth being about 35 feet. The water is plentiful and excellent, and rises within 9 to 25 feet of the surface. There are some good springs along the valley sides. Flowing waters are found deep in the limestone by gas borings, but the ordinary water wells do not reach sufficient depths to procure water from this source.

Lapel.—Lapel, situated on Stony Creek near the west edge of the county, has a few shallow wells which obtain water from the till, but most of them are drilled into the limestone. The drift is here 30 to 70 feet deep, and the limestone waters are pure and in little danger of pollution. The common rock wells are only 30 to 59 feet deep. A few of the deeper limestone wells have obtained flowing waters, described above as in artesian area 62 (p. 169), but most of the wells do not flow.

Orestes.—Orestes has no waterworks system, and the supply is all from private wells. Most of the wells are dug and penetrate only 15 to 25 feet into the surface deposits, in which plenty of water is found; but this water is very easily polluted and is a source of great danger where used. Many drilled wells go into limestone, which is here within 50 to 60 feet of the surface, and the waters obtained are both abundant and pure. The drilled wells average about 70 feet in depth.

Ingalls.—Ingalls lies between Lick and Fall creeks in the southwest corner of the county and has a few dug wells, though the driven and drilled wells are more in favor. There are, perhaps, a dozen wells which reach the limestone, which is found at depths of 80 to 100 feet. The rock here seems to be unusually free from openings, and some of the rock wells can be pumped dry, though many yield large volumes of water. A few old gas wells have obtained flowing waters from the limestone. Driven wells 40 feet in average depth

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 260.

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are most used, and the water, which comes from a gravel bed in the till, is plentiful and good.

Other communities.—The following table contains a list of other villages in Madison County, with particulars regarding their water supply:

Other village supplies in Madison County.

Town.	Population (1900).	Source.	Depth to rock.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Alliance	.....	Wells, dug and drilled.	26	130	26	.....	.....	Gravel.
Chesterfield	164	Wells, driven and drilled.	20	400	22	110	0-30	Gravel and limestone.
Dundee	175	Wells, drilled and dug.	18	100	75	18-50	10-20	Do.
Emporia	61	Wells, driven and dug.	12	80	60	110	10-30	Gravel.
Fishersburg	250	Wells, drilled and driven.	35	140	75	30-70	.....	Gravel and limestone.
Florida	98	Wells, driven and dug.	25	65	35	.....	.....	Gravel.
Gilman	400	.....do.....	13	60	45	64	10	Do.
Leisure	100	Wells, dug and drilled.	20	55	25	25	9	Limestone or gravel.
Linwood	100	Wells, dug and driven.	18	89	25	.....	.....	Gravel.
Markleville	225	Wells, dug and drilled.	14	115	20	100	.....	Gravel and limestone.
New Columbus	.....	Wells, dug and drilled; springs.	32	120	33	140	3	Gravel.
Perkinsville	318	Wells, drilled and driven.	20	130	.....	80-100	.....	Gravel and limestone.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Madison County and analyses of their waters. The last column in each table gives numbers referring to identical wells in the other table

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Records of typical wells in Madison County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Feet.*	*Gallons.*	*° F.*	
1	Public supply	Alexandria	350	Drilled	10	110		Limestone				4
2	W. B. Leeson	do	42	do	3	42		do	28		50	8
3	Joseph White	do	98	do	3			do	28			7
4	Alexandria Paper Co	do		do	8		+ 2	do		20		
5	Perry Heritage	1½ miles NE. of Alexandria		do	8		+ 3	do	125	20		
6	Norton Brewing Co	Anderson	275	do	8	270	−22	do				9
7	Harry Bevan	do	180	do	3	180	−40	do	60			
8	Hill Machine Co	do	32	Driven	6	26	−24	Gravel				
9	Grand Hotel	do	60	Drilled		58		do				12
10	Union Building	do	250	do	6		−20	Limestone				10
11	J. B. Hook	Dundee	93	do	3			do	55			
12	Elwood Water Co	Elwood	150	do	8		−20	do	60			} 16
13	do	do	400	do	8		−20	do	60			
14	American Sheet and Tin Plate Co	do	350	do	4			do	40–60			15
15	American Shovel and Tool Co	do	180	do	8			do	60			14
16	Charles T. Gooding	2¾ miles NE. of Frankton	39½	do	3	39½	+ 1½	do	9			
17	Daniel Abbott	2 miles NE. of Frankton	365	do	8	70	+10	do	4	90		
18	Odd Fellows	Gilman	45	Driven				Gravel				18
19	J. W. Higgs	Ingalls	90					Limestone				19
20	Cleveland, Cincinnati, Chicago, and St. Louis R. R.	do	40	Drilled	1½		−15	Gravel				20
21	Earl Woodward	Lapel	107	do	2	107	−20	Limestone	80			
22	David Conrad	do	50	do	2	50	−12	do	48			21
23	Robert Wilson	do	900	do	8	125	+ 4	do	35	45		
24	Paris Wisler	Leisure	50	do	2	50	−10	do				22
25	Jacob Capps	New Columbus	900	do	8		+ 3	do		5		24
26	E. S. Plackard	Orestes	107	do	3½	100	− 5	do	50			
27	William Revis	do	18	Dug		16	− 8	Gravel				25
28	Frank Detraz	Pendleton	140	Drilled	4			Limestone	20			26
29	J. P. Jones	do	30	do	4			do	3			27
30	F. W. Egelus	Perkinsville	130	do	3	130	−10	do	80			28
31	Public supply	Summitville	347	do	8		− 0	do	100			29
32	R. B. Carll	do	30	Dug		30		Gravel				30
33	E. Homer Howard	do	60	Drilled		60		do				31

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Mineral analyses of waters in Madison County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	J. Moody	Alexandria	Well, 72 ft.	Lake Erie and Western R. R.	Nov., 1902			3.5		152	72		29	201		109	103					
2	Mr. Booth	do	Well, 67 ft. by 2 in.	do				2.5		142	50		22	263		76	63					
3		do	Well, 1,000 ft. by 8 in.	do	Sept., 1904					83	29		5.9	186		15	6.8					
4	City supply	do	Drilled wells	do		Limestone	35	16		26	8.3		43	40		77	33				370	1
5	do	do	do	Dearborn Drug and Chemical Co.	Aug., 1900	do	17	2.5		71	32	17		168		44	17				344	
6		do	Pipe Creek	do			14	2.2		119	49	214		265		55	327				1,052	
7	Joseph White	do	Drilled well, 98 ft. by 3 in.	H. E. Barnard	Oct., 1907	Limestone		.40		22	53			.0	335	190	62	5.0	0.001	2	805	3
8	W. B. Leeson	do	Drilled well, 42 ft. by 3 in.	do	do	do		.40		134	33			.0	342	158	44	3.00	.002	0	704	2
9	T. M. Norton Brewing Co.	Anderson	Drilled well, 275 ft. by 8 in.	Wahl & Henius.	Oct., 1900	do				75	34	1.4(?)				12	7	.0			385	6
10	Union Building.	do	Drilled well, 250 ft. by 6 in.	Chase Palmer	July, 1907	do	22	2.6		56	35	13		.0	273	58	12	.07			347	10
11		South Anderson	Well, 60 ft.	Lake Erie and Western R. R.			5.6	8.4		104	14	24		190		36	12				401	
12	Grand Hotel	Anderson	Drilled well, 60 ft.	H. E. Barnard	Sept., 1907	Gravel	.0			140	24			.0	316	134	23	2.50	.004	0	566	9
13	American Shovel and Tool Co.	Elwood	Old gas well, drilled.	(?)		Limestone	1.2	6.8		77	30	6.7		173		30	10				344	
14	do	do	Drilled well, 180 ft. by 8 in.	(?)		do	11	.77		121	38	4.3		160		176	6.7				523	15
15	American Tin Plate Co.	do	Drilled well, 350 ft. by 8 in.	(?)		do	16	5.5		82	37	13		179		59	19				440	14
16	Elwood Water Co.	do	Drilled wells, 150 and 400 ft.	H. E. Smith		do		2.4		84	33	16		213		16	4.8	.0				12, 13
17	City supply	Frankton	Well, 20 ft.	H. E. Barnard	Sept., 1907			.0		111	.0			.0	305	148	23	2.50	.020	2	650	
18	Odd Fellows	Gilman	Driven well, 45 ft.	do	Oct., 1907	Gravel		1.4		25	42			.0	413	37	17	.100	.001	4	488	18

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Mineral analyses of waters in Madison County—Continued.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorate (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
19	J. W. Higgs	Ingalls	Drilled well, 90 ft.	H. E. Barnard	Oct., 1907	Limestone		0.8		83	29			0.0	306	7	2	0.100	0.000	0	360	19
20	Cleveland, Cincinnati, Chicago and St. Louis R. R.	do	Well, 40 ft. by 1¼ in.	do	do			1.2		103	28			.0	241	61	112	.000	.001	4	738	20
21	David Conrad	Lapel	Drilled well, 50 ft. by 2 in.	do	Sept., 1907	Limestone		.01		115	0.0			.0	360	141	35	.000	.000	0	468	22
22	Paris Wisler	Leisure	Drilled well, 50 ft. by 3½ in.	do	Oct., 1907	do		.10		110	0.0			.0	362	88	22	.100	.000	0	482	24
23		Mounds Park	Spring	do	do			.80		71	28			.0	305	51	7	.100	.001	0	332	
24	Jacob Capps	New Columbus.	Old gas well	do	do	Limestone		1.00		57	25			.0	326	28	6	.000	.000	33	294	25
25	Wm. Revis	Orestes	Open well, 18 ft.	do	Sept., 1907	Gravel		.00		97	33			.0	324	237	89	10	.001	2	1,024	27
26	F. Detraz	Pendleton	Drilled well, 140 ft. by 4 in.	do	Oct., 1907	Limestone		.0		69	32			.0	271	63	8.5	4.00	.001	5	580	28
27	J. P. Jones	do	Drilled well, 30 ft. by 4 in.	do	do	do		.0		14	38			.0	303	197	1.0	1.50	.000	9	494	29
28	F. W. Egelus	Perkinsville	Drilled well, 130 ft. by 3 in.	do	Sept., 1907	do		.14		76	5			.0	307	86	44	.000	.080	0	412	30
29	City supply	Summitville	Drilled well, 347 ft. by 8 in.	Dearborn Drug and Chemical Co.	Mar., 1903	do	17	3.9		93	28	17		209		16	14				402	31
30	R. B. Carll	do	Open well, 30 ft.	H. E. Barnard	Oct., 1907	Gravel		.0		45	72			.0	340	271	168	2.00	.005	0	1,192	32
31	E. Homer Howard.	do	Drilled well, 60 ft.	do	do	Limestone		1.4		42	36			.0	214	21	14	.200	.000	0	488	33

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MARION COUNTY.

SURFACE FEATURES AND DRAINAGE.

Marion County is at the south edge of the area here under discussion, and in the middle north-south tier of counties. It has a total area of 400 square miles and is about 20 miles in each dimension, the only irregularity in outline being a slight eastward projection of the northeast corner. Indianapolis, the county seat, is also the state capital, and is by far the largest city in Indiana.

The surface of the county is a dissected plateau with the highest portions in the northwest and southwest corners. The range of elevation is from about 660 feet, at the lowest point in the White River valley, to somewhat more than 850 feet at Lawrence, and at the point where Marion, Hamilton, and Boone counties meet. (See Pl. I.)

White River crosses the county from north to south, and with its tributaries drains almost its entire area. The depth of the valley varies in different parts of the county as the elevations of the adjacent uplands vary, but is generally deeper in its lower course. At Riverside Park the morainic bluffs rise about 75 feet above the stream. The flood plain is broad, though generally less than a mile in width, but 10 to 25 feet above it there is along the entire river course within the county a broad gravel terrace, at many points 2 or 3 miles wide, though narrower at some places. Indianapolis lies on this terrace.

The largest tributary of White River is Fall Creek, joining it from the northeast. In this county the courses of these two streams are roughly parallel. Eagle Creek, which comes in from the northwest and joins the White below Indianapolis, has throughout its course a well-developed flood plain and valley. Near Traders Point the stream flows more than 50 feet below the uplands.

Buck Creek flows south along the southeast edge of the county and drains about 45 square miles of surface into East Fork of White River. All these streams have many small tributaries which drain the surface very thoroughly. There are no natural lakes worthy of mention.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Alluvial materials occupy the bottoms of all the larger valleys, and vary in importance with the size of the streams. Another class of alluvial beds of much importance in this county comprises the stratified gravels which lie above the present flood plain of White River and form the great flat terrace, averaging perhaps 2 miles in width,[a] upon which Indianapolis is situated. The alluvial beds

[a] Leverett, Frank, Wells of southern Indiana: Water-Supply Paper U. S. Geol. Survey No. 26, p. 26.

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furnish enormous quantities of water to wells wherever they occur. It has been estimated that in Indianapolis alone there are 25,000 wells, and all but a small part of this number are in the alluvium. The wells yield sufficient water for domestic uses, and many of the gravel wells produce large quantities of water for industrial purposes. Open gravel beds may be encountered at various depths, but those near the surface should be avoided as much as possible unless the wells are situated at some distance from possible sources of pollution.

As shown in Plate I, about half the surface of the county is covered with glacial moraine, occurring in three separate areas. East of White River the moraine surface is characteristic, consisting of low undulating hills, which, however, in few places stand more than 50 feet above their surroundings. West of this river the morainic character of the surface is less strongly shown, though in many places it is unmistakable. The conditions for obtaining wells in the moraines are very irregular, and the depth of wells at any given place depends to a great extent upon the amount and thickness of the gravel beds in the drift. For driven or drilled wells, gravels or sands must be penetrated, and the depth ranges from 10 or 15 to 200 feet, depths of 50 or 60 feet being common. Open or dug wells are used to a considerable extent, and these are supplied by seep waters from the clayey drift.

The relative area of surface covered by till is less important here than in any other county of this region south of Wabash River (Pl. I). Nevertheless, the till has been encountered by all borings that have gone through the surface deposits, and is probably continuous, over the rock, throughout the county. As in the moraines, dug wells supplied by the slow-moving waters of the clay are very common. Within recent years it has become generally understood that drilled wells are almost certain to find gravel beds from which more plentiful and better water can be had, and most new wells are of this type. The water table in the till fluctuates noticeably with the seasons, and for unfailing open wells it is necessary to dig below the permanent water level. Deep drilled or driven wells are unaffected by dry spells.

CONSOLIDATED MATERIALS.

The "Niagara" limestone in Marion County is everywhere overlain by younger rocks. Deep borings and our general knowledge of the structure of the rocks indicate that it extends continuously below the entire county and is 200 to 275 feet thick. It is of much the same character as it is farther to the north and east where surface outcrops occur. All wells in the "Niagara" encounter abundant waters which enter from well-defined openings. In Indianapolis many wells are supplied by these waters, but there the "Niagara" is overlain by the Devonian limestones and the wells are cased only

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to the top of the Devonian. Consequently, the waters obtained represent a mixture from the two formations, and it was difficult to get unmixed samples from either horizon.

East of Indianapolis the Devonian limestones are the youngest rocks. The records of drillers commonly class all limestones above the "Niagara" as "Corniferous," and this term will be used in the well logs. The limestone, from 40 to 50 feet thick, is very porous and open, and is sometimes spoken of as "honeycomb limestone."

The Devonian limestones yield good supplies of water, but they are drilled easily, and most drilled wells go through them to procure additional waters from the underlying "Niagara." No unmixed samples of water from these rocks could be obtained, but a number of analyses of waters from both the "Niagara" and "Corniferous" are given in the table on pages 185–186.

The New Albany shale underlies the drift in most of the south and west portions of the county. The shale is a very poor water producer, and wells which reach it have little chance of obtaining good water supplies unless the boring is continued through to the limestone below. At Bridgeport, near the top of this formation, the shale is 124 feet thick.

The "Knobstone" group, consisting of shales and sandstones, is thought to underlie the extreme southwest corner of the county. No wells were found which have penetrated these beds.

ARTESIAN AREAS.

There is a single district in Marion County in which flowing wells have been procured. This area lies west of Traders Point, along the creek bottom and on the slopes near by. (Pl. IV, No. 63.) Although a number of flowing wells have been obtained, one, much better than the others (No. 20 in the table on p. 184), is 87 feet deep and penetrated a gravel bed in the moraine. The water will rise 16 feet above the surface, and the flow at 2 feet above the surface is about 8 gallons per minute.

CITY AND VILLAGE SUPPLIES.

Indianapolis.—The Indianapolis water supply system, owned by the Indianapolis Water Company, a private corporation, was installed in 1870, a part of the water being taken from White River, and part from deep drilled wells. The river water is drawn from the lake formed by a dam at Broad Ripple Park, and carried by canal to filter beds near the Riverside pumping station. The filtration removes most of the matter in suspension, and materially reduces the number of bacteria present. About 60 per cent of the city water

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is supplied from the river. The remainder is obtained from wells at the Riverside pumping station, where the company owns 254 acres of carefully guarded land, on which the sanitary conditions are excellent. There are 33 drilled wells, most of which are situated along two lines, though a few of them are scattered. All are drilled into limestone, which is entered at 60 to 90 feet below the surface, and the depths range from 273 to 364 feet. The wells will yield about 16,000,000 gallons per day. When first drilled, in 1896, the water in the wells stood 8 feet above the low-water level of the river, but has now dropped to 32 feet below low-water level.

In August, 1898, a number of the wells were tested, and 25 delivered a normal yield of 18,694,583 gallons daily. In the same month, of three wells tested with a 90-foot air lift, No. 1 yielded 1,297,344 gallons per day, No. 2 yielded 1,323,195 gallons, and No. 3 yielded 1,263,805 gallons. The water from all the wells is pumped by air lift to the surface, but both the well and the filtered water is pumped by direct pressure into the mains. There are 282 miles of mains from 4 to 36 inches in diameter, and 18,863 services are in use, with 2,291 fire hydrants. About 140,000 people are supplied, and the average daily pump of both well and river water is 17,883,800 gallons.

Altogether the supply is a very satisfactory one. The health of the city is good, and there has been much less trouble with typhoid fever than there was when private wells furnished the supply.

Indianapolis has long been known as a city especially favored by the abundance of the underground water supply. Before the installation of the public water system every family owned a private well, and it is estimated that there are still 25,000 wells in use. Most of these are drilled or driven and obtain water from gravel beds which occur at various depths, all being good water bearers. In that part of the city which lies east of the river there are two distinct water zones in gravel, the upper, at 45 to 60 feet in depth, called the first gravel, and another at 70 to 80 feet, known as the second gravel. In the flat west of the river the first-gravel water is found at 12 to 20 feet below the surface, and the second gravel at about 50 feet. In almost all wells the first-gravel waters are polluted, for in all thickly settled areas it is inevitable that much organic matter and sewage should enter the ground, and some of this enters the shallow wells. A great deal of sickness is without question due to the use of wells of this class. The second-gravel waters are much safer, as they are protected above by a layer of clayey till, but many sanitary analyses indicate that even these wells contain organic matter. Many of them, however, supply an abundance of good water. The following is the log of a second-gravel well, the analysis of whose water is No. 8 in the table on page 185.

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Log of Parry Manufacturing Company's well at Indianapolis.

	Feet.
Gravel	60
Blue clay	4
Gravel	11
	75

A number of other well logs are given by Leverett [a] in his report on the wells of southern Indiana.

Another and much superior class of water is that supplied by deep-drilled wells from the limestone. In Indianapolis the rock lies from 80 to 120 feet below the surface, and does not outcrop at the surface within many miles of the city. It is protected from contamination from above by a considerable thickness of till, and the chances of pollution from the surface are remote. There are, perhaps, 300 rock wells in the city, most of them used by manufacturing establishments or by office buildings. Two rock divisions may be entered, the "Corniferous" limestone, to a thickness of about 50 feet, and next below it the "Niagara" limestone. A number of analyses of rock waters in Indianapolis are given in the table on pages 185–186. These waters are all drawn from both formations, as the wells are cased only to the surface of the "Corniferous," while the borings go into the "Niagara." A well at the Deaf and Dumb Asylum is reported to have penetrated the following materials:

Log of well at the Deaf and Dumb Asylum.

	Ft.	in.
Depth of dry well	20	10
Gravel, clay, etc	78	8
Shale	3	6
Limestone	172	
Porous blue rock (water)	35	10
Hard rock	3	..
	313	10

The analysis of this water is to be found on page 185, No. 13.

No records of strata in deep borings at Indianapolis could be obtained, but the following logs are from gas borings at Broad Ripple, 7 miles north of the statehouse, and at Bridgeport, 9 miles southwest:

Section of well at Broad Ripple.[b]

	Feet.
Drift	55
Corniferous limestone	48
Niagara limestone	257
Hudson River and Utica	504
Trenton limestone	24
	888

[a] Op. cit., p. 28.

[b] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 237.

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Section of well at Bridgeport.[a]

	Feet.
Drift	140
Devonian shale	124
Corniferous limestone	40
Niagara limestone	200
Hudson River limestone and shale	475
Trenton limestone	74
	1,108

Brightwood.—Brightwood is a part of Indianapolis, but is supplied by a separate water system, owned by the city. The water is obtained from two drilled wells 130 feet deep, and one well 380 feet deep, and is pumped to an underground reservoir holding 40,000 gallons. Direct pressure is used, and the system has 31,500 feet of mains. There are 400 consumers and about 93,000 gallons per day are used. The present supply is adequate for ordinary uses, but it gives insufficient fire protection.

Fort Benjamin Harrison.—Fort Benjamin Harrison, situated a few miles northeast of Indianapolis, was completed in 1907, and has its own water system. In 1907 there were four deep wells, of which three were drilled for water, and the fourth was an old gas well, plugged at 318 feet. The rock here lies at a depth of 195 feet, and the water is all taken from the limestone. Elaborate tests of the capacity of these wells have been made, and the four pumped together will yield about 120 gallons per minute. The log of one well is as follows:

Log of well at Fort Benjamin Harrison.

	Feet.
Soil	20
Hard gray sandy clay	40
Same with some gravel	40
Hardpan	40
White quartz sand (water-bearing)	35
Quicksand	3
Brown limestone (?)	7
Gray gravel, sand, and clay	10
Disintegrated limestone (water-bearing)	15
Brown sandy limestone	45
Gray limestone (plentiful water)	120
Shale	20
Hard limestone	7
	417

The water is pumped to two standpipes, and distributed by gravity, and the supply is expected to be sufficient for the demands of the fort.

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 237.

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OTHER COMMUNITIES.

The following table contains a list of other villages in Marion County, with the conditions of their water supply:

Village supplies in Marion County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Acton	460	Wells, dug and driven.	22	40	35	.....	.....	Gravel.
Ben Davis	100	Wells, dug and drilled.	15	125	20 and 100	.....	.....	Sand and gravel.
Bridgeport	375	Wells, dug, driven, and drilled.	10	80	60	.....	.....	Do.
Broad Ripple	487	Wells, drilled and dug.	20	150	60	40–90	.....	Sand, gravel, and limestone.
Castleton	199	.....do.....	6	112	20	.....	− 8	Gravel.
Clermont	276	.....do.....	14	200	20	.....	−15	Do.
Cumberland	310	.....do.....	15	240	140	240	.....	Sand, gravel, and limestone.
Flackville	27	Wells, dug and driven.	15	50	30	.....	.....	Sand and gravel.
Glens Valley	52	.....do.....	30	60	50	.....	.....	Gravel.
Howland Station	100	Wells, driven.....	25	50	40	.....	.....	Do.
Lawrence	385	Wells, dug.....	10	30	20	200	.....	Gravel and till.
New Augusta	215	Wells, drilled and dug.	14	110	90	.....	− 3	Gravel.
New Bethel	.....	Wells, driven, drilled, and dug.	20	118	60	.....	.....	Do.
Nora	70	Wells, driven and dug.	12	100	95	80	.....	Gravel and limestone.
Oaklandon	300	Wells, dug and drilled.	11	150	20	160	− 8	Gravel.
Southport	285	Wells, dug and driven.	10	40	35	.....	.....	Sand and gravel.
Traders' Point	50	Wells, dug and drilled.	20	87	25	.....	+16 and − 5	Do.
Valley Mills	145	.....do.....	15	135	20	.....	.....	Gravel.
West Newton	500	.....do.....	15	215	55	184	.....	Do.

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TYPICAL WELLS AND ANALYSES.

The following tables give detailed information regarding typical wells in Marion County and analyses of their waters. The last column in each table gives the numbers of identical wells in the other table.

Records of typical wells in Marion County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Analysis No.
			Feet.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Gall.*	
1	C. W. Heady & Son..	Broad Ripple...	43	Drilled..	3	42	− 8	Gravel.....	43	.....	1
2	N. Morris Simons....	Carmel.....	156	...do.....	2	150	−40	Limestone .	120	.....	....
3	W. C. Rush.....	Flackville.....	32	Driven.....	....	32	....	Gravel.....	....	.....	2
4	Deaf and Dumb Asylum.	Indianapolis....	313	Drilled..	8	310	−30	Limestone .	99	.....	13
5	National Starch Co...	.....do.....	380	...do.....	8	370	−18	.....do.....	98	.....	12
6	Indiana Abattoir Co.	.....do.....	300	...do.....	8	....	−15	.....do.....	....	.....	....
7	Majestic Office Building.	.....do.....	217	...do.....	8	200	−45	.....do.....	....	.....	15
8	Pope Motor Car Co...	.....do.....	80	...do.....	4	80	−16	Gravel.....	....	.....	....
9	Western Cold Storage and Ice Co.	.....do.....	354	...do.....	8	190	−30	Limestone .	100	.....	14
10	Home Brewing Co ...	.....do.....	365	...do.....	8	....	−60	.....do.....	....	.....	7
11	Indianapolis Brewing Co.	.....do.....	300	...do.....	6	....	−70	.....do.....	....	.....	16
12	Noelke-Richards Iron Works.	.....do.....	300	...do.....	8	230	−70	.....do.....	....	.....	6
13	Indianapolis Cold Storage Co.	.....do.....	376	...do.....	10	....	−46	.....do.....	100	.....	....
14	Indianapolis Light and Heat Co.	.....do.....	350	...do.....	10	325	−20	.....do.....	100	.....	....
15	Interior Hardwood Co.	.....do.....	405	...do.....	4	370	−18	.....do.....	124	.....	....
16	Capital Rattan Co....	.....do.....	400	...do.....	6	110	−19	.....do.....	100	.....	23
17	Advance Veneer and Lumber Co.	.....do.....	303	...do.....	6	185	−60	.....do.....	85	.....	25
18	Soldiers and Sailors Monument.	.....do.....	270, 160	...do.....	8	....	−42	.....	....	.....	24
19	Augustus Bowen.....	Nora.....	77	...do.....	3	70	−28	Gravel.....	78	.....	....
20	Everet Mavel.....	Traders Point..	87	...do.....	2	87	+16	.....do.....	....	8	....

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Mineral analyses of waters in Marion County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	C. W. Heady & Son.	Broad Ripple.	Drilled well, 43 ft. by 3 in.	H. E. Barnard.	Sept., 1907	Gravel	....	0.80	....	117	26	....	....	0.0	315	69	33	0.00	.001	2	488	1
2	W. C. Rush	Flackville	Driven well, 70 ft.	do		do	....	.20	....	84	16	....	....	.0	267	57	40	.00	.001	0	308	3
3	L. S. Ayres & Co.	Indianapolis	Well, 300 ft.	T. W. Smith.	Sept., 1906		22	39		120	44	85		199	....	138	130	....	....	....	793	....
4	United States Encaustic Tile Co.	do	Well, 60 ft. by 6 in.	Dearborn Drug and Chemical Co.	Jan., 1903		7.2	2.0	....	123	31	26	....	207	....	112	21	....	....	....	539	....
5	Merchants' Light and Heat Co.	do	Well, 274 ft. by 10 in.	do			13	1.4	....	142	45	46	....	248	....	147	51	....	....	....	697	....
6	Noelke-Richards Iron Works.	do	Drilled well, 300 ft. by 8 in.[a]	do	Apr., 1906	Limestone	32	118	....	76	34	28	....	216	....	19	6.7	....	....	....	....	12
7	Home Brewing Co.	do	Drilled well, 365 ft. by 8 in.	do		do	12	7.7	....	130	42	34	....	233		107	51	....	....	....	....	10
8	Parry Manufacturing Co.	do	Well, 75 ft. by 8 in.	do	1905.	Gravel	11	2.1	....	106	31	11	....	163	....	111	17	....	....	....	460	....
9	State Life Building.	do	Drilled well, 188 ft.	do		Limestone	10	2.2	....	127	46	83	....	187	....	230	99	....	....	....	793	....
10	American Brewing Co.	do	Drilled wells, 205 ft.		April, 1907	do	15	.0	.0	143	46	41	....	....	....	113	99	.00	....	....	747	....
11	Central Power Co.	do	Drilled well, 240 ft. by 8 in.			do	1.4	3.9	....	63	34	32	....	210	....	3.2	10	....	....	....	366	....
12	National Starch Co.	do	Drilled well, 380 ft. by 8 in.	C. S. Miner		do	7.4	2.0	....	127	47	....	....	....	....	96(?)	50	....	....	....	792	5
13	Deaf and Dumb Asylum.	do	Drilled well, 313 ft. by 8 in.		Feb., 1905.	do	19	Tr.	....	96	35	11	....	223	....	19	10	....	....	....	414	4
14	Western Cold Storage and Ice Co.	do	Drilled well, 354 ft. by 8 in.[b]			do	7.2	11	....	119	44	21	....	227	....	100	31	....	....	....	....	9
15	Majestic Office Building.	do	Drilled well, 217 ft. by 8 in.	E. Martin		do	....	32	....	43	23	....	....	....	....	34	Tr.	Tr.	....	....	360	7

[a] Water from 230 feet.

[b] Water from 190 feet.

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Mineral analyses of waters in Marion County—Continued.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2)	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
16	Indianapolis Brewing Co.	Indianapolis	Drilled well, 175 ft. by 6 in.		1906.	Limestone	28	14	....	175	52	....	....	620(?)	....	91	78	Tr.	....	....	537	11
17	....	do	Pogues Run[a]	Lake Shore and Michigan Southern R. R.	....	....	....	3.2	....	86	30	24	....	147	....	100	27	0.0	....	....	....	....
18	....	do	do[b]	do	....	....	....	....	....	91	32	27	....	171	....	96	25	....	....	....	....	....
19	....	do	White River[c]	do	Feb., 1904	....	....	2.7	....	68	24	5.5	....	129	....	42	8.5	11	....	....	....	....
20	City supply	do	City drilled wells.	do	Dec., 1907	....	....	....	....	85	31	31	....	169	....	54	48	....	....	....	....	....
21	Columbia Conserve Co.	do	Well, 315 ft.	No Scale Co.	....	....	9.6	3.4	....	70	46	7.9	....	205	....	24	12	....	....	....	....	....
22	Do	do	Well, 180 ft.	do	....	....	14	2.2	....	78	44	7.9	....	205	....	38	12	....	....	....	401	....
23	Capital Rattan Co.	do	Drilled well, 400 ft.[d]	Chase Palmer.	July, 1907.	Limestone	14	.3	....	60	36	60	.0	344	95	18	2.5	....	....	466	16
24	Soldiers and Sailors' Monument.	do	Drilled wells, 270 and 160 ft.	do	do	do	18	Tr.	....	104	48	60	.0	310	186	80	21	....	....	720	18
25	Advance Veneer and Lumber Co.	do	Drilled well, 303 ft. by 6 in.[e]	do	do	do	16	.2	....	64	27	30	.0	406	5.6	5.2	2.7	....	....	365	17
26	Frank Fox	New Augusta	Well, 143 ft.	H. E. Barnard.	Sept., 1907	....	....	.00	....	95	18	....	.0	299	124	10	.30	.000	2	328	....

[a] Average of four analyses. [b] High stage. [c] Normal stage. [d] Water from 110 feet. [e] Water from 185 feet.

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MARSHALL COUNTY.

SURFACE FEATURES AND DRAINAGE.

Marshall County lies along the west edge of the area here under discussion and is in the second tier of counties south of the Michigan-Indiana line. It measures about 22 miles from east to west and 21 miles from north to south, and is therefore almost square. The total area is 440 square miles, and as the population in 1900 was 25,119, there were 57 inhabitants to the square mile. Plymouth, the county seat, is 108 miles north of Indianapolis and 75 miles southeast of Chicago.

The county is essentially plateau-like. The total range in elevation is but little more than 100 feet. The lowest point is in the Tippecanoe Valley in the southeast corner; several points on the west and north edge are more than 850 feet above sea level (Pl. I). The east half of the county is a monotonous plain, varied only by a few small areas of low moraine; the west half is largely occupied by the Maxinkuckee moraine, which extends southward from St. Joseph River through St. Joseph and Marshall counties and into Fulton County. This moraine, though of characteristic topography, is not of great relief, and in few places stands more than 50 feet above the bordering plains.

Along the west edge of the county is an irregular belt of flat surface, which is part of the bed of the glacial Lake Kankakee, and this abandoned basin is now a sandy plain.

Yellow River enters the county near its northeast corner and flows southwest in a zigzag course, draining almost three-fourths of the surface. In its course across the Maxinkuckee moraine the valley is in some places 40 to 50 feet below the bordering uplands, but in the till plain near Bremen it is much shallower. The flood plain does not generally exceed one-fourth mile in width.

Tippecanoe River crosses the southwest corner of the county through the till plain, and is fed by a number of small tributaries with shallow valleys.

A branch of Kankakee River heads in the moraine in the northwest corner of the county, and with its tributaries drains an area of about 40 square miles. The stream valleys are all small and shallow.

There are many lakes in Marshall County, all of which occupy basins in the moraine itself or in bordering areas where the drainage has been obstructed by the moraines. Most of the lakes are small, but the largest, Lake Maxinkuckee, in the southwest corner of the county, is about 2 square miles in area, and has a maximum depth of 76 feet. The lake, which is fed by springs and the drainage from a small area of the surrounding hilly moraine, has become popular as a summer resort, on account of its excellent boating, bathing,

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and fishing, and, besides the villages of Culver and Maxinkuckee, a considerable part of the shore line is occupied by residences and hotels. The other lakes are all much smaller, and most of them are shallow.

The northeast portion of the county was originally very poorly drained and largely occupied by marshes, and although there is still some wet ground, surface ditches and tiling have helped to bring much of the land under cultivation. Locally there are small marshes in poorly drained depressions in the moraine.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Valley alluvium occurs to some extent along the banks of Yellow and Tippecanoe rivers. In the Yellow River valley the deposits range in width from one-fourth mile to almost nothing in the vicinity of Bremen. Along the west edge of the county there is a sand plain which was formerly the bed of a lake. Locally small dunes of wind-blown sand occur in the moraine near the old lake bed, and the sand in some places is still moving.

The surface of the entire eastern half of the county has more or less stratified gravel and sand. This covers the till and is so intermingled with it that the area has been classified by Mr. Leverett (Pl. I) as gravelly till and will be described under this heading.

All the types of alluvium mentioned are found either on flat plains of incomplete or sluggish drainage or in the valley lowlands. In either situation wells are easily obtained. Driven wells, 10 to 25 feet deep, are common, and the yield is abundant for ordinary domestic or farm uses. Such a well can often be sunk in a few hours and at a very small cost.

Morainal drift covers much of the west half of the county, and small areas in the east half. For successful driven or drilled wells in the moraine it is necessary to sink to open beds of gravel or coarse sand, and as these occur irregularly, they may be near the surface or considerably below it. As a rule the water table in the moraine is farther from the surface than on the plains, owing to the greater relief, and thus requires wells of greater depths. Where open beds are struck, however, the waters are abundant and pure. Artesian wells occur at many points in the moraine and are described below.

The till plains are found in the east half and the northwest corner of the county. A few deep borings have shown over 200 feet of till, and this is probably about the average thickness, exclusive of the overlying deposits. The till extends uninterruptedly below the moraines and the alluvial beds. Near the surface an unusual amount of gravel and sand is incorporated with and overlies the till, and this condition holds throughout the county.

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The till plains of this county are particularly favored by the abundance and availability of their underground waters. Wells range from 15 to 40 feet in depth and generally pass through thin layers of sand and till into gravel. Driven wells are commonly used and are very satisfactory, affording good protection from surface pollution.

ARTESIAN AREAS.

Area 64 (Pl. IV) includes the valley of Yellow River for some distance above and below Plymouth, and although the valley is here scarcely more than one-eighth of a mile in width, twenty or thirty flowing wells have been obtained in it. All the flowing waters have been reached in gravels, but below the valley alluvium, for it is necessary to go through till to reach artesian waters. Flows have been obtained at various depths. At the old grist mill a gravel bed at a depth of only 28 feet yields strong flows. The wells at the waterworks procured artesian waters at depths of 50 to 60 feet and between 125 and 200 feet, and the volume of flow varies greatly from season to season. The head of the waters is from the surrounding moraine and the source can not be more than a few miles from the wells. Analyses of the waters from several wells in Plymouth are given in the table on pages 194–195.

Area 65 (Pl. IV) forms a narrow belt along the north and east shores of Lake Maxinkuckee. The flows all occur along the lowlands not more than 25 feet above the level of the lake, and as the moraine rises rather abruptly from the shores, the artesian belt is of small extent. Perhaps the best flows have been obtained at Culver Military Academy, just north of the town of Culver. There are about a dozen flowing wells on the grounds, each of which discharges 10 to 50 gallons or more per minute. The wells are 10 to 50 feet deep and the head is about 6 feet above the surface. The artesian waters are obtained in gravel underlying clayey drift.

In other places within this artesian area the flows are obtained at depths of 15 to 200 feet, and all have about the same head. The gravel beds in which the waters are under pressure probably come to the surface somewhere in the higher parts of the moraine, and the water that enters there acquires sufficient head in moving downward toward the lake to flow from wells that penetrate to it. No flows can be expected on ground more than 20 to 25 feet above lake level.

Area 66 (Pl. IV) includes a narrow belt of land running south and east from Donaldson along the foot of the moraine area. Several flowing wells have been obtained in gravel below pebbly clay at depths of 30 to 75 feet. The flows are rather weak, and yield only a few gallons per minute.

Area 67 (Pl. IV) has a situation similar to that of area 66, and these two may prove to be continuous. The conditions of flow are

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furnished by gravel beds in the moraine, which dip to the west below impervious clay beds. In the vicinity of Teegarden these gravel beds extend out beneath the gravelly plain, and nearly every household in that village has a flowing well. The head is commonly only a foot or two above ground, and some wells will flow only in the cellars below the level of the surface. The strongest well in the village (No. 19 in the table, p. 193) has a head 8 feet above ground and flows about 6 gallons per minute at that height. The common depth for wells is 30 to 50 feet, although some are deeper. A continuation of this flowing-well area extends westward from Teegarden along Yellowbank Creek, and along this valley flows have been obtained from gravel below till, at depths of 50 to 100 feet.

The valley of Yellow River near Bremen and for several miles below it (Pl. IV, No. 68) has furnished a number of flowing wells. At Bremen the water in a few wells rises to the surface and flows a little in wet seasons, and other wells to the southwest flow constantly, though none yield a large volume. The water is found in gravel below glacial clay at depths of 50 to 75 feet.

Several flowing wells are reported from the lowlands between Argos and Tippecanoe (Pl. IV, No. 69), the water being obtained from gravel beds beneath till. It is probable that the head of the waters is from the moraine to the east. The pressure is sufficient to cause flows only in favored localities.

CITY AND VILLAGE SUPPLIES.

Plymouth.—The city of Plymouth owns its excellent water supply, taken from flowing wells. The first three wells were drilled about 1888, and are still in use, and in 1895 nine additional wells were drilled. The water from all these is flowing for at least a part of the year, and in wet seasons the natural yield is sufficient to supply the demands. In dry seasons the yield is less and the requirements are greater, so the wells are then pumped by air lift. The early wells were from 126 to 196 feet deep, but wells of the later series are all less than 60 feet deep. In 1907 it was decided to put in an additional deep well, which was sunk in August of that year. It was learned at a later date that this well had entered shale, into which it was bored for some distance. No adequate supply of water was obtained from this material. At the time the town was visited (August 16, 1907) this well was reported to have penetrated the following materials:

Log of well at city waterworks, Plymouth.

	Feet.
Clay	9
Sand and gravel	180
Clay	23
Limestone	2
Shale	107
Limestone.	

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From the wells the water flows or is pumped by air lift to an underground reservoir 24 feet in diameter and 14 feet deep. From this it is pumped by direct pressure into 8, 6, and 4 inch mains, of which 7¾ miles are now in use. There are about 430 service taps and 52 fire hydrants, and almost half of the people avail themselves of this supply. Records of the city wells are Nos. 15 and 16 in the table on page 193, and analyses of the waters are Nos. 16, 17, and 18 in the table on pages 194–195.

There are very few dug wells in Plymouth. Most of the private wells are drilled or driven, and 50 feet is the usual depth. Along the river valley there are many flowing wells, already described as in area 64 (p. 189). In the higher parts of town the same waters may be obtained, and they are also under artesian pressure, the water standing at about the same level as that to which it will rise in the flowing wells. The gravel waters are protected above by the impervious clay bed, and the supply is excellent.

Bremen.—At Bremen the waterworks, built by the city in 1893, are supplied by five driven wells, 4 and 6 inches in diameter, which obtain water from a depth of 60 feet. The water is obtained from gravel after sand, clay, and hardpan have been penetrated, and rises to about the level of the ground. One well was drilled to shale at 180 feet, but less water was found at that depth than at the 60-foot gravel horizon. The water is forced into a standpipe 104 feet high and holding 1,000 barrels, and from this it is distributed by gravity. There are about 7 miles of 6, 4, and 2 inch mains and 320 taps. It is estimated that 600,000 gallons a day are used to supply about 75 per cent of the population.

Most of the private wells in Bremen are driven, and range from 15 to 110 feet in depth, with 50 feet as the common depth. In some of these the water flows at the surface (area 68, p. 190), while in most it stands a short distance below ground. All the water is drawn from gravel below clay, and the supply of the deeper wells is protected from pollution.

Argos.—The Argos water system is owned by the city and was built in 1897. A single well, 120 feet deep and 6 inches in diameter, furnishes the entire supply, which is obtained from a gravel bed beneath glacial clay. The principal water-bearing bed was found at a depth of 80 feet, the water rising within 20 feet of the surface. The water is pumped to an 800-barrel underground reservoir, and from this by direct pressure into the mains. About 86 taps and 27 fire plugs are supplied by 18,800 feet of 6 and 4 inch mains, and 800 barrels of water are used per day. Only one-fifth of the people of the town use this supply.

About 80 per cent of the population of Argos use private wells, almost all of which are driven and from 20 to 100 feet deep, though

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most of them strike abundant water in gravel at 30 feet, and this water rises within 20 feet of the surface. The driven wells are very satisfactory and never fail unless obstructed in some way.

Bourbon.—The Bourbon waterworks are owned by the Union Water, Light, and Power Company and were installed in 1897. The water is obtained from two drilled wells, 8 inches in diameter and 150 feet deep, which reach a gravel bed after penetrating alternating layers of sand, till, and gravel. Deep-well pumps are used to lift the water into a standpipe 100 feet high and holding 2,100 barrels, and the water is distributed from this by gravity. Connections are so made that direct pressure can be used in case of fire. Only 70 services are supplied by this company, which furnishes water to about one-seventh of the people of the town. The average amount pumped daily is 1,500 barrels.

In Bourbon there are a great many private wells, and practically all are driven from 16 to 60 feet deep, averaging about 20 feet. The head of the water is from 3 to 30 feet below ground.

Culver.—The town of Culver, on Lake Maxinkuckee, installed a public water system in 1907. The stock of the company is owned by the town and by individuals, with the understanding that the town is to buy all of the stock. Three 4-inch wells have been drilled, and the contract has been let for a 6-inch well. The water is obtained from a gravel bed 70 feet below ground and rises within 12 feet of the surface. A pneumatic pressure tank is used and the water is distributed by the expansion of the compressed air in the tank, into which the water is forced by a 20-horsepower gasoline engine. Only 5 taps and 15 fire hydrants had been installed at the time of visit (September 23, 1907).

Drilled wells are the prevailing type in Culver. They are 10 to 135 feet deep, the average depth being about 70 feet. A few wells in the lowlands flow, but most of the town lies on the moraine considerably above the lake level, and the waters in few wells rise nearer than 12 feet to the surface. The waters come from gravel beds in the moraine and are good.

Other communities.—The following table contains a list of other villages in Marshall County, with particulars in regard to their water supply:

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Other village supplies in Marshall County.

Town.	Population (1900).	Source.	Depth of wells.			Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.		
			Feet.	*Feet.*	*Feet.*	*Feet.*	
Ayr	86	Wells, driven	40	100	60	.....	Gravel.
Burr Oak	200	.....do	30	90	50	.....	Do.
Donaldson	110	.....do	15	80	60	0 to −15	Do.
Harris Station	.....	.....do	15	30	20	.....	Do.
Inwood	279	.....do	12	85	25	.....	Do.
Lapaz	311	.....do	40	50	40	.....	Do.
Maxinkuckee	105	.....do	80	140	100	−10 to −20	Do.
Rutland	64	.....do	20	50	25	−10 to −15	Do.
Teegarden	150	.....do	35	50	40	+ 8 to − 3	Do.
Tippecanoe	304	.....do	20	40	30	−10 to −15	Do.
Tyner	167	Wells, driven and dug	17	145	30	−10 to −15	Do.
Walnut	141	Wells, dug	15	20	15	− 4 to −10	Do.

TYPICAL WELLS AND ANALYSES.

The two following tables give detailed information regarding typical wells in Marshall County and analyses of their waters. The last column in each table gives numbers referring to identical wells in the other table.

Records of type wells in Marshall County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Galls.*	*° F.*	
1	Public supply	Argos	120	Drilled	6	80	−20	Gravel	.....	.....	.....	1
2	.....do	Bourbon	150	...do	8	150	−36	...do	.....	.....	.....	2
3	.....do	Bremen	60	Driven	4 and 6	60	0	...do	.....	.....	.....	4
4	Amos Friend	Burr Oak	60	...do	2	60	−50	...do	.....	.....	.....	5
5	Public supply	Culver	70	Drilled	4	70	−12	...do	.....	.....	.....	7
6	C. E. Hayes	.....do	18	Driven	1¼	18	.....	...do	.....	.....	.....	8
7	Culver Military Academy.	.....do	30–50	...do	2	.....	+ 6	...do	.....	80–100	.....	6
8	Charles Johnston	Donaldson	.....	...do	.....	.....	+	...do	.....	2	.....	9
9	Township well	2 miles E. of Donaldson.	50	...do	2	50	+ 3	...do	.....	.....	.....	...
10	Andreas Bros	Hibbard	45	...do	1¼	45	.....	...do	.....	.....	.....	10
11	D. T. Warnacut	Inwood	30	...do	1¼	30	.....	...do	.....	.....	.....	11
12	H. Y. Shirk	Lapaz	45	...do	1¼	45	0	...do	.....	.....	.....	12
13	Marshall County.	Marshall County Infirmary.	86	Drilled	4	86	−28	...do	.....	.....	.....	13
14	J. W. Wilson	Maxinkuckee	128	Driven	2	120	−20	...do	.....	.....	.....	14
15	Plymouth waterworks.	Plymouth	126–196	Drilled	6	.....	0	...do	.....	.....	.....	17
16	.....do	.....do	50–60	...do	2 and 4	50	+	...do	.....	.....	.....	18
17	Wm. Zehner	.....do	28	...do	12	28	+ 4	...do	.....	300	.....	15
18	G. E. Kimmel	Rutland	49	Driven	1¼	45	−10	...do	.....	.....	.....	...
19	Jacob Hildebrand	Teegarden	45	...do	1¼	45	+ 8	...do	.....	6	51	19
20	J. E. Johnson	Tyner	45	...do	1¼	45	−10	...do	.....	.....	.....	20
21	Plymouth waterworks.	Plymouth	322+	Drilled	.....	.....	.....	.....	213	.....	.....	...

46448°—WSP 254—10——13

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Mineral analyses of waters in Marshall County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Public supply	Argos	Drilled well, 120 ft. by 6 in.	H. E. Barnard	1907	Gravel	...	1.6	...	83	28	...	...	0.0	332	0.0	14	1.0	.020	9	272	1
2	do	Bourbon	Drilled well, 150 ft. by 8 in.	do	1907	do	...	1.6	...	65	26	...	...	.0	306	.0	12	.5	.001	4	354	2
3	J. W. Brougher	Bremen	Driven well, 65 ft. by 2 in.	do	1907	do	...	1.0	...	139	18	...	...	.0	161	16	13	6.00	.00	9	314	....
4	Public supply	do	Driven wells, 60 ft. by 6 in.	do	1907	do	...	.2	...	116	27	...	..	.0	289	42	30	6.00	.00	19	582	3
5	Amos Friend	Burr Oak	Driven well, 60 ft. by 2 in.	do	1907	do	...	.01	...	119	25	...	...	.0	379	103	30	6.0	.001	2	554	4
6	Culver Military Academy.	Culver	Driven well, 50 ft. by 2 in.	do	1907		...	.3	...	113	25	...	...	.0	286	8.6	2.0	.30	.001	52	252	7
7	Public supply	do	Drilled wells, 70 ft. by 4 in.	do	1907	Gravel	...	.1	...	74	28	...	...	.0	268	17	2	.10	.001	33	294	5
8	C. E. Hayes	do	Driven well, 18 ft. by 1¼ in.	do	1907	do	...	.01	...	88	29	...	...	.0	301	20	10	4.00	.001	2	408	6
9	Charles Johnston	Donaldson	Driven well	do	1907	do	...	.20	...	65	25	...	...	.0	245	25	9	.01	.001	9	306	8
10	Andreas Bros	Hibbard	Driven well, 45 ft. by 1¼ in.	do	1907	do	...	.80	...	78	31	...	...	.0	310	70	12	1.00	.00	4	404	10
11	D. T. Warnacut	Inwood	Driven well, 30 ft. by 1¼ in.	do	1907	do	...	.01	...	114	32	...	...	.0	300	37	52	8.0	.001	2	644	11
12	H. Y. Shirk	Lapaz	Driven well, 45 ft. by 1¼ in.	do	1907	do	...	.00	...	89	43	...	...	.0	331	62	33	1.2	.001	0	488	12
13	Marshall County	Marshall County Infirmary.	Drilled well, 86 ft. by 4 in.	do	1907	do	...	.0	...	85	32	...	...	.0	302	36	8	.2	.001	2	396	13
14	J. W. Wilson	Maxinkuckee	Driven well, 128 ft. by 2 in.	do	1907	do	...	.2	...	69	25	...	...	.0	268	6.6	1	.20	.06	19	344	14
15	Wm. Zehner	Plymouth	Drilled well, 28 ft. by 12 in.	do	1907	do	...	.2	...	68	24	...	...	.0	301	21	5	.00	.001	4	278	17
16	City supply	do	Drilled wells, 40 to 200 ft.	Lake Shore and Michigan Southern R. R.	1904	do	...	2	.7	61	27	9	.1	169	....	Tr.	1.3	.....	.....	...	.....	....

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17	.....do.....	.....do.....	Drilled wells, 126 to 196 ft.	R. B. Dole....	1907	...do.....	21	.4	...	37	23	1	7	.0	242	2.3	1.5	.8	.....	...	207	15
18	.....do.....	.....do.....	Drilled wells, 50 to 60 ft.	.....do.....	1907	...do.....	18	3.8	...	61	30	7	.4	.0	326	3.6	.2	1.5	.....	...	285	16
19	Jacob Hildebrand.....	Teegarden.....	Driven well, 45 ft. by 1¼ in.	H. E. Barnard	1907	...do.....	...	.0	...	98	41	...	...	.0	398	17	9	.01	.001	0	394	19
20	J. E. Johnson.....	Tyner.....	.....do.....	.....do.....	1907	...do.....	...	.0	...	111	35	...	...	.0	336	78	32	18	.00	9	586	20
21	A. Nelians.....	Walnut.....	Open well, 14 ft.....	.....do.....	1907	...do.....	...	.01	...	150	41	...	...	.0	418	96	21	3.5	.001	2	720	....

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MIAMI COUNTY.

SURFACE FEATURES AND DRAINAGE.

Miami County occupies the geographic center of the area discussed in this report. It is 30 miles long from north to south, and 12 wide, except in the southern portion, where a projection extends 4 miles to the east. The area is 375 square miles, and the population in 1900 was 28,344, or 75 to the square mile. Peru, the county seat, is 68 miles north of Indianapolis.

All of the area which does not lie in the valleys of the larger streams is classed as uplands, though the large streams and their branching tributaries have done much to dissect the plain. The surface slopes from both the north and south portions of the county toward Wabash River, which, at the west county line, is about 640 feet above sea level. The highest point is at the north edge, with an elevation of about 880 feet, making a total range in the county of about 250 feet.

Wabash River, which, with its tributaries, receives all the surface drainage from the county, crosses it centrally from east to west, and has a deep, broad valley, with a wide flood plain. At Peru the valley floor is 1½ miles broad and is more than 100 feet below the divide between Wabash and Eel rivers. There are rock outcrops along the lower valley on the south side of the river, but most of the deepening has been in the unconsolidated deposits.

Eel River, which joins the Wabash at Logansport, crosses the north half of Miami County in a northeast-southwest direction. Its valley is well developed but is neither so deep nor so broad as that of the Wabash.

Mississinewa River enters from the east to join the Wabash above Peru. The valley is narrow and canyon-like, 100 feet deep in places, and rock outcrops along the sides show that the stream has cut its channel 30 feet into the limestone.

Big Pipe Creek and Deer Creek cross the south portion of the county, and, with their tributaries, afford good drainage to the plateau. The valleys are much shallower than those of the three rivers mentioned above.

Miami County is almost devoid of natural lakes or marshes. This is rather remarkable when account is taken of the fact that its north end lies on a great moraine ridge which in the counties farther north and east is dotted with lakes. The well-developed drainage of this moraine by Eel River and its tributaries is, in part, the cause of this absence of poorly drained areas.

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GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The deposits of valley alluvium are of considerable importance, especially along the Wabash Valley. Here the gravels form not only the present flood plain of the river, but the extensive terraces above it. The city of Peru lies on the lowest terrace, and there are remnants of another terrace 30 feet above this one. On the flood plain at Peru the alluvium is from 15 to 25 feet thick; on the higher terrace it is much deeper, because of both the greater elevation above the stream and the sloping rock surface, which here dips to the north. Wells in the valley east and west of Peru have penetrated 40 to 60 feet of gravel. There are alluvial beds of some importance along the valleys of Eel and Mississinewa rivers and Big Pipe Creek, but they are all of smaller area and in general are thinner than the deposits of the Wabash Valley. The alluvium everywhere yields abundant water, and hundreds of wells are supplied by it. In sparsely settled districts these wells may be good, but in towns the waters from alluvium are liable to pollution, as surface drainage readily enters the porous material. Peru has a great many wells in alluvium, the shallow wells being particularly dangerous. Large numbers of cesspools drain into the gravel, and liquid matter from them finds its way to shallow wells.

That portion of the county which lies north of Eel River is almost entirely occupied by a broad moraine belt (Pl. I). There is also a small strip of this moraine between Wabash and Eel rivers, and another belt extends into the west and southwest part of the county. The topography of the main moraine belt is characteristic, the surface consisting of irregular knolls of sandy or gravelly drift or of the typical pebbly clay. The outlying moraine areas are similar but of a milder type. In the moraines water-bearing gravels or coarse sands are usually encountered at depths of 30 to 60 feet, although in some wells it is necessary to go deeper. The presence of impervious clay above the water-bearing bed is a guaranty against the commoner forms of contamination, and the waters, though hard, are always cool and palatable. Some dug wells obtain less desirable supplies by seepage from the clays near the surface.

The two principal till-plain areas, one of which lies between Wabash and Eel rivers and the other in the east and southeast parts of the county (Pl. I), were continuous before Wabash River cut its valley through them. The till is everywhere less than 100 feet thick south of the Wabash Valley, but is deeper to the north. Many wells 200 feet deep have failed to reach rock, and one well pierced over 300 feet of unconsolidated material.

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Most wells in the till are dug and supply small quantities of water. Drilled wells that penetrate to considerable depths are becoming more and more common, and these are sunk to beds of gravel; and in the south half of the county many wells go through the till into the rock below.

CONSOLIDATED MATERIALS.

Throughout this entire county the surface deposits are immediately underlain by limestones of Silurian age. The term "Niagara" is commonly applied to all these limestones, though undoubtedly the younger limestone, the Kokomo ("water lime"), which outcrops at Kokomo, is present in part of the area. Well drillers do not distinguish between the two formations. There are many rock wells south of Peru and a few north of that city, all of which furnish abundant water obtained in the fractured upper portion of the formation or in openings in the body of the rock. Some of the openings are several inches in diameter, as shown by the way in which the drill will drop when openings are struck. Analyses of rock waters from various localities are given in the table on pages 203–204.

ARTESIAN AREAS.

Artesian area 70 (Pl. IV) includes a belt in the north part of Peru, the first terrace above the Wabash River flood plain, where several wells flow in small volume. At the factory of the Peru Canning Company are five drilled wells 67 feet deep, the water bed being a stratum of gravel. The wells flow at the surface when not pumped, but when in use the head of these wells and of all others in the neighborhood is lowered below the surface.

Flowing wells occur along Wabash River a few miles west of Peru. (Pl. IV, No. 71.) The largest of these wells, on the farm of G. M. Tillett, generally known as the "Flowing Well farm," was drilled for gas. The important flow of water is from the "Niagara" limestone and was reached 90 feet below the surface. When drilled the well was cased through this limestone, and salt water from the "Trenton" limestone rose within 4 feet of the well mouth. The casing was later pulled, and an analysis of the water (No. 20, p. 204) shows that the "Trenton" water does not enter into the present flow to a noticeable extent. This well was capped down to 1¼ inches, from which opening the water rises 22 feet above the surface. The force of the water lifted the pipe 14 inches out of the ground in two years, but when the cap was removed, the pipe settled back in two days. It now flows 600 gallons per minute. The drive pipe is 44 feet long and reaches to the limestone. The following materials were penetrated by this well:

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Log of flowing well on farm of G. M. Tillett, near Peru.

	Feet.
Clay and gravel	44
Limestone	420
Shale	425
Trenton limestone	12
	901

There are several other flowing wells within a few miles, but none of them approaches this one in volume of flow.

Area 72 (Pl. IV) includes the lowlands in the vicinity of Deedsville. Here there are a few wells that flow continuously and several more that flow only in wet seasons. All the flows have been obtained from gravel beds in the moraine at depths of 30 to 60 feet. An analysis of the water from one of these wells is given in the table on page 203.

Area 73 (Pl. IV) includes the valley of a small creek west of Bunker Hill. The artesian waters come from the limestone, which here lies comparatively close to the surface, and the wells are drilled into the rock. One well flows at 8 feet above ground and yields about 4 gallons per minute. An analysis of the water is No. 1 in the table on page 203.

Flowing wells occur along the valley of Deer Creek and one of its tributaries. (Pl. IV, No. 74.) At Miami the limestone from which the artesian waters come is reached at a depth of 35 to 40 feet but is somewhat deeper in the valley to the east. The best wells are about 100 feet deep, and the water, of good quality, has everywhere a temperature of about 52° F. The wells flow somewhat more copiously in wet seasons than at other times.

Driven wells in the creek bottom south of Santa Fe have obtained flows at shallow depths (Pl. IV, No. 75) from gravel in the till. The yield is small and the conditions for flows are very local.

CITY AND VILLAGE SUPPLIES.

Peru.—The public water system of Peru is owned by the city and was installed in 1878, the water being drawn in part from wells and in part from Wabash River. Fourteen wells, situated on the south side of the river and above the city, are in use; they are 8 inches in diameter and about 350 feet in average depth. The water is drawn from the "Niagara" limestone and is good, though rather high in salt from the intrusion of the salty "Trenton" rock waters from poorly plugged gas wells. The wells furnish about 75 per cent of the water used, the remainder being pumped directly from Wabash River. The river receives sewage from Wabash, Huntington, and other towns above, and this impure water is mixed with the well water and contaminates the whole supply. At the time the city was visited it was having another well drilled, and enough wells are to be sunk in the near future to furnish all the water.

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The water from the wells and the river is pumped to a reservoir 93 feet higher than the pumping station and having a capacity of 1,200,000 gallons. It is distributed by gravity to 24 miles of mains and 1,765 taps. About 1,300,000 gallons daily are needed to supply 65 per cent of the inhabitants. For fire protection the river water is pumped by direct pressure into the mains.

Large numbers of private wells, mostly driven or drilled, are in use in Peru. The depth to limestone ranges from 0 to 100 feet, and the wells obtain water from either the rock or the alluvial gravels. Near the river rock wells are common, but the rock surface becomes lower to the north, and the thicker gravels furnish driven wells with plentiful water. The rock waters are good, as are those from the deep gravels, but shallow gravel wells are dangerous and should be abandoned. A deep boring for oil just south of the city limits gives the following section:[a]

Log of deep boring at Peru.

	Feet.
Drift	10
Water lime and Niagara limestone	455
Clinton (?) limestone	15
Hudson River and Utica	449
Trenton limestone	27
	956

Converse.—The town of Converse owns its own public water system, which is supplied by a drilled well 8 inches in diameter and 240 feet deep. The well penetrated 192 feet into the limestone, and the water rises within 10 feet of the surface. An analysis of this water is No. 3 in the table on page 203. From the well the water is pumped by steam to a tank 72 feet high and holding 1,000 barrels, from which it is distributed by gravity. There are about 2 miles of 8, 6, and 4 inch mains, and 60 per cent of the people require 200,000 gallons per day. The water is pure and wholesome.

The private wells of Converse are dug, driven, and drilled, and range from 10 to 200 feet deep, though 60 feet is the average depth. The water stands about 10 feet below the surface, and the wells never fail. Limestone is entered at depths of 45 to 50 feet, and much of the water is obtained from the rock.

Denver.—Denver has no public water supply, and each family has a private well. These are almost all driven wells, from 10 to 60 feet deep, and though the average depth is only about 25 feet the supply is abundant. The driven wells penetrate gravel beds in the glacial deposits, and the limestone that is encountered at 45 to 100 feet below ground has always furnished plentiful supplies of water to the drilled wells that have gone into it.

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 254.

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Bunker Hill.—Bunker Hill lies on a belt of low morainal drift. The wells are driven, drilled, or dug, and the common source of supply is the limestone, which is here encountered at 65 to 83 feet below the surface. The driven wells obtain gravel waters from shallow depths and are in constant danger of pollution from the cesspools of the town. The gravel wells are comparatively safe, but the rock wells are best protected from contamination, and the water is of excellent quality.

Other communities.—The following table contains a list of other villages in Miami County, with particulars in regard to their water supply:

Other village supplies in Miami County.

Town.	Population (1900).	Source.	Depth to rock.			Depth to rock.	Head above (+) or below (−) surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Amboy	402	Wells, drilled and dug.	20	45	25	14–45	− 8	Limestone.
Bennetts Switch.	133	Wells, dug and drilled.	15	96	20	72	.....	Gravel and limestone.
Chili	245	Wells, drilled and dug.	18	80	65	.....	.....	Gravel.
Courter	.....	....do.....	20	110	80	.....	−15 to −25	Do.
Deedsville	112	Wells, driven, drilled, and dug.	10	65	30	.....	+ 2 to −	Do.
Loree	30	Wells, drilled and dug.	20	120	100	80	−20 to −30	Gravel and limestone.
Macy	314	Wells, drilled, driven, and dug.	20	230	110	.....	−20 to −40	Gravel.
McGrawsville	40	Wells, drilled and dug.	20	110	100	.....	−18	Gravel and limestone.
Miami	244	Wells, driven, dug, and drilled.	8	105	10	36	− 8	Do.
Nead	21	Wells, bored, drilled, and dug.	20	105	.....	85	.....	Do.
North Grove	316	Wells, drilled	80	100	85	70	− 8	Limestone.
Perrysburg	86	Wells, driven, dug, and drilled.	20	156	50	.....	.....	Gravel.
Pettysville	47	Wells, driven	40	75	60	.....	−30	Do.
Reserve	95	Wells, drilled and dug; and springs.	20	205	100	0–60	.....	Limestone.
Santa Fe	92	Wells, drilled and dug.	14	110	100	70–80	.....	Gravel and limestone.
Wagoner	105	Wells, drilled, driven, and dug.	15	170	100	.....	.....	Sand and gravel.
Wawpekong	205	Wells, drilled	100	130	110	79–95	−14	Limestone.
West Peru	.....	Wells, driven and drilled.	10	130	12	20	.....	Gravel and limestone.

TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Miami County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

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Records of typical wells in Miami County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Temperature.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Feet.*	*Gallons.*	*°F.*	
1	A. L. Weckler	Bunker Hill	172	Drilled	4	150	−45	Limestone	85			1
2	Clem Graves	¼ mile NW. of Bunker Hill	140	do	4		+ 8	do	14	4		2
3	Public supply	Converse	240	do	8		−10	do	48			3
4	Oscar Moody	Deedsville	34	Driven	1½			Gravel				4
5	J. E. Milliron	Denver	35	Dug and driven	1½	35		do				5
6	Mrs. S. A. Morgan	Macy	230	Drilled	2	230	−40	do				7
7	Public well	do	75	do	2			do				6
8	F. M. Tracy	Mexico	130	do	4							9
9	B. Herrell	Miami	105	do	4		+ 8	Limestone	36	1½	52½	10
10	L. M. Reeder	do	10	Dug			− 8	Gravel				11
11	F. F. Morris	Nead	105	Drilled	4			Limestone	85			8
12	J. W. Eltzroth	North Grove	82	do	2	82	− 8	do	70			12
13	Chas. A. Rannells	Perrysburg	56	Driven	2			Gravel				13
14	Brubaker & Criuer	do	156	Drilled	4		−10	do				
15	Peru Canning Co	Peru	67	do	5	65	+ 0	do				
16	Peru Ice and Cold Storage Co	do	214–300	do	4		−15	Limestone	−14			
17	G. M. Tillett	5 miles W. of Peru	901	do	8	90	+22	do	44	600	51½	20
18	J. O. Cole	West Peru	12	Driven	1¼	12	− 0	Gravel				19
19	F. K. Baber	Pettysville	74	do	2	50	−45	do				21
20	David Behney	Reserve	110	Drilled				Limestone	65			22
21	Levi Baker	Wagoner	170	do	2	170		Gravel				23
22	Public supply	Peru	500	do	8							

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Mineral analyses of waters in Miami County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	A. L. Weckler	Bunker Hill	Drilled well, 172 ft. by 4 in.	H. E. Barnard	1907	Limestone		3.2		71	37			0.0	370	0.0	5	0.05	0.04	4	562	1
2	Clem Graves	3½ miles W. of Bunker Hill.	Drilled well, 140 ft. by 4 in.	do	1907	do		.01		66	38			.0	375	8	6	.05	.001	0	428	2
3	Public supply	Converse	Drilled well, 240 ft. by 8 in.	do	Oct., 1907.	do		.40		90	25			.0	322	97	8	.05	.001	4	456	3
4	Oscar Moody	Deedsville	Driven well, 34 ft. by 1¼ in.	do	Nov., 1907.	Gravel		2.0		120	40			.0	324	109	38	.10	.00	9	596	4
5	J. E. Milliron	Denver	Dug and driven well, 35 ft.	do	Sept., 1907.	do		.0		86	27			6.0	218	68	10	.50	.00	0	434	5
6	Public well	Cloud's store, Macy.	Drilled well, 75 ft. by 2 in.	do	do	do		4.0		119	38			.0	368	9	18	.05	.001	19	484	7
7	Mrs. S. A. Morgan	Macy	Drilled well, 230 ft. by 2 in.	do	do	do		3.2		58	.0			.0	289	.0	3.0	18	.001	19	252	6
8	F. F. Morris	Nead	Drilled well, 105 ft. by 4 in.	do	1907	do		.01		108	41			.0	356	23	8.0	.3	.003	9	406	11
9	F. M. Tracy	Mexico	Drilled well, 47 ft. by 4 in.	do	Sept., 1907.	do		.04		86	27			14	222	23	9.0	2.00	.001	4	394	8
10	B. Herrell	Miami	Drilled well, 105 ft. by 4 in.	do	Nov., 1907.	do		.10		104	34			.0	297	9.0	3.0	.10	.00	5	352	9
11	L. M. Reeder	do	Open well, 10 ft.	do	do	do		.0		83	28			.0	200	145	45	.00	4.0	8	466	10
12	J. W. Eltzroth	North Grove	Drilled well, 82 ft. by 2 in.	do	Oct., 1907.	Limestone		1.6		83	27			.0	332	98	6	.05	.04	6	422	12
13	C. A. Rannells	Perrysburg	Driven well, 56 ft. by 2 in.	do	Sept., 1907.	Gravel		.12		71	22			.0	177	47	21	.05	.00	23	322	13
14		Peru	Wabash River[a]	Lake Shore and Michigan Southern.	Mar., 1907.					46	14	44		69		38	77	5.4				
15		do	Pipe Creek?	do				3.2		69	21	3.2		137		28	2.8	6.0				
16	Public supply	do	Drilled well, 500 ft. by 8 in.	do	Mar., 1907.					90	30	41		164		51	75	6.2				

[a] High stage.

[b] Average of four samples.

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Mineral analyses of waters in Miami County—Continued.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
17	Peru Canning Co.	Peru	Drilled well, 67 ft. by 5 in.	R. B. Dole	Aug., 1907.	Gravel	23	2.8	....	91	34	9.6		0.0	350	76	2.2	Tr.	.....	....	392	....
18	Peru Ice and Cold Storage Co.	.....do.....	Drilled wells, 214 to 300 ft.	.....do.....	...do.....	Limestone	18	2.3	0.6	162	52	36	7.4	.0	360	318	48	4.8	.....	....	835	....
19	J. O. Cole	West Peru	Driven well 12 ft. by 1¼ in.	H.E. Barnard.	1907	Gravel	....	1.4	....	134	38	....	....	.0	316	53	84	.05	.001	50	360	15
20	G. M. Tillett	5 miles W. of Peru.	Drilled well, 90 ft.[a]	.....do.....	1907	Limestone	....	.6	....	101	30	....	....	.0	287	42	12	.1	.001	20	366	17
21	F. K. Baber	Pettysville	Driven well, 74 ft. by 2 in.	.....do.....	Sept., 1907.	Gravel	....	.1	....	85	25	....	....	.0	226	24	2	8.00	.001	4	356	19
22	D. Behney	Reserve	Drilled well, 110 ft.	.....do.....	1907	Limestone	....	.6	....	119	44	....	....	.0	290	33	35	8.0	.010	4	434	20
23	Levi Baker	Wagoner	Drilled well, 170 ft. by 2 in.	.....do.....	Sept., 1907.	Gravel	....	4.0	....	106	31	....	....	.0	336	.0	1.5	.7	.001	60	288	21

[a] Water at 90 feet.

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ST. JOSEPH COUNTY.

SURFACE FEATURES AND DRAINAGE.

St. Joseph County is in the extreme northwest corner of the area under consideration, its north boundary being formed by the Indiana-Michigan state line. It has an area of 460 square miles, and had in 1900 a population of 58,881, more than half of which was in South Bend, the county seat. The average population per square mile was 128.

The county has a topography of great diversity, and the uplands, which in most counties include the greater part of the area, are here of small extent as compared with the lowlands, which occupy almost half of the surface. The uplands include only those areas mapped as moraine or till (Pl. I), and are confined to the southeast corner of the county and to scattered areas along the north edge. The small moraine-covered districts north of Kankakee River and east of the St. Joseph and the district extending south and east from South Bend have the rolling, somewhat irregular surface characteristic of moraines, though the till-covered portions are flat. The lower valleys of St. Joseph and Kankakee rivers are less than 700 feet above sea level, but the till plain in the southeast corner rises to more than 850 feet, giving a range in elevation in the county of over 150 feet.

There is a low flat area west of South Bend, on both sides of Kankakee River, that was once the bed of a lake. Much of the former lake bed is marsh, and although artificial drainage has resulted in the reclamation of a part of it, there is still an extensive marsh north of Kankakee River. The valley of St. Joseph River is also a broad belt of lowlands several miles wide.

St. Joseph River, the most important stream of the county, enters from the east, and flowing west to South Bend there turns sharply north into Michigan. The valley is several miles wide, and during the retreat of the last glacier was filled with alluvial gravels. The stream now occupies a narrow valley which it has cut into the gravels. The river has no important tributaries in this county.

Kankakee River heads in the Kankakee marsh within a few miles of the St. Joseph, and the divide between the two drainage systems is a low inconspicuous gravel flat. Kankakee River has a low gradient through its marshy basin.

The plain east of the Maxinkuckee moraine is drained by small streams which are tributary to Yellow River.

In the west half of the county are many small lakes of two distinct types. Those of one type, in the old Lake Kankakee bed, are shallow and bordered by marshes, and the basins were formed by the unequal accumulation of organic deposits in the marsh; those of the other type, in kettles or depressions in the moraine, are surrounded by low hills of glacial drift and are less marshy.

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GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

An important belt of alluvium, 2 miles or more in width, lies along the St. Joseph River valley. The valley is filled with this material to a great depth, and the river has now intrenched itself in its own deposits which lie as broad terraces on either side. The lake-bed deposits of the Kankakee marsh are sands and gravels, but are finer and more perfectly stratified than the stream-laid materials and the sands form a larger proportion of their entire thickness. A third class of alluvium, found as outwash aprons beyond the edges of some of the moraines (Pl. I), overlies till plains or alluvial beds of river origin and is thickest near the moraines and thins out away from them.

All the alluvial beds are good water bearers. Shallow driven wells are much used, and the water, though in places of doubtful sanitary quality, is abundant and well suited for industrial purposes. The wells are easily polluted by drainage from cesspools or from the surface, as there is rarely a protecting bed of clay above.

The distribution of the moraines in the county is shown in Plate I, and the topography is of the irregular hill and hollow type characteristic of such deposits, though the relief is not great. The moraines were deposited on top of till, and their thickness is determined in few places, as well drillers fail to recognize the transition from moraine to the underlying glacial deposits. Many shallow dug wells are in use in the moraines, water being obtained from the clayey drift. Other drilled and driven wells penetrate to water-bearing gravel beds, which are found as deep as 100 feet below the surface. These wells are free from surface drainage and furnish excellent water, but the shallow wells are undesirable on account of the likelihood of contamination.

The till plain which occupies southeastern St. Joseph County is level and featureless. The till is continuous between the other surface deposits and the rock throughout the county, though it covers only one-fourth of the surface. Its thickness has been determined at only a few points, but probably averages about 200 feet. Many dug wells get small supplies of water from the till itself or enter gravel in the till at depths of 30 feet or less. If gravels are found the supply is plentiful, though as readily subject to pollution as the water from other open wells. Deeper gravels can as a rule be found by sinking tubular wells, which shut out the objectionable surface waters. These gravels afford the best available source of water in the till areas.

ARTESIAN AREAS.

Artesian area 76 (Pl. IV) includes the lowlands near St. Joseph River in South Bend and somewhat north of that city. The waters in a wider belt are under artesian pressure, but flows occur only on

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the low ground close to the stream. The best known of the flowing wells are at the two city pumping stations. The central station has 35 wells, all from 112 to 116 feet deep, and the flowing water comes from a gravel bed below till; at the north station there are 34 flowing wells, the water in which is doubtless from a continuation of the same gravel bed that supplies the wells at the central station, but this bed is only 87 feet below ground. The head of the wells at both stations is sufficient to cause flows when the pumps are idle, but when they are in operation the water stands considerably below the well mouth. At the central station the heavier pumping reduces the head of the waters for some distance in all directions, as shown by other wells supplied from the same gravel bed. The new wells at the plant of the Indiana and Michigan Electric Company, 200 yards from the pumping station and across the river from it, are influenced by the pumping of the city wells, and the head of the waters in them varies from +2 to −2 feet, according to the amount pumped from the wells across the river. The effect on surrounding wells is less marked at the north station, as the natural head of the waters is greater. A well in the park less than 100 yards from the city wells flowed 150 gallons per minute at a height of 8 feet above the ground at a time when the city pumps were at work. Flows have been obtained in the river valley as far north as St. Mary's Academy.

Area 67 (Pl. IV), described in part for Marshall County (p. 189), contains many flowing wells east and southeast of North Liberty. Eight flows are reported from a single farm. The wells are all on low ground, and the flowing waters come from a gravel bed at a depth of 60 to 80 feet, the head being from the moraine to the east.

CITY AND VILLAGE SUPPLIES.

South Bend.—The city of South Bend owns and operates its public waterworks, the water being drawn from about 70 drilled wells (area 76). There are two pumping stations, one of which, the central station, is on the river bank near the center of the city. The wells here are 112 to 116 feet deep and 4 to 10 inches in diameter. The pumping at this station is done either by water power from St. Joseph River or by steam. The north station, near the river at the north edge of the city, is supplied by about 34 drilled wells 6 to 10 inches in diameter and 87 feet deep. These wells also flow when the pumps are not running. Steam pumps are used at this station.

The water from both sets of wells is forced into a standpipe 225 feet high and holding 33,000 gallons. It is distributed from this standpipe by gravity. There are 80 miles of mains 4 to 24 inches in diameter, and 7,000 taps supply about 75 per cent of the people of the city. The average daily pump of the central station is 2,500,000 gallons, and of the north station 2,820,000 gallons. The capacity

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of the two stations is 14,000,000 gallons per day, but the wells will not furnish this amount of water, and new wells were being drilled at the central station in the fall of 1907. The city has also purchased 5 acres of land near the river, one-half mile below the north station, and it is planned to install an additional pumping station at this place. Analyses of water from the city wells are Nos. 12, 17, and 18 in the table on pages 213–214.

A great many private wells are in use in South Bend, both for domestic and industrial purposes. The town is located on a broad alluvial flat, and abundant water can everywhere be obtained by dug or driven wells at shallow depths. Most wells for family use are driven, averaging about 30 feet deep, and in these the water is abundant, but all analyses show much organic matter, and the presence of sewage in the upper-gravel waters is almost inevitable, as there is no protective covering of clay. The waters should never be used for domestic purposes. For manufacturing uses the waters are very satisfactory, although rather hard. Large quantities are obtained by building large, loosely curbed dug wells. A much safer water may usually be obtained from gravel at depths of 60 to 80 feet, beneath a layer of clay. A combination dug and drilled well at the Studebaker plant gave the following section:

Section of combination well at Studebaker plant, South Bend.

	Feet.
Sand and gravel	32
Coarse gravelly sand	8
Coarse sand, finer than that above	12
Rather fine angular sand	5
Coarse gravelly sand	4
Fine sand	4
Sandy blue clay	11
Fine blue clay	14
Fine quicksand	4
Sandy gravel	9
	103

A deep gas well near that given above penetrated the following materials:

Section of deep gas well, South Bend.[a]

	Feet.
Drift	160
Subcarboniferous and Hamilton shale	220
Corniferous limestone	60
Lower Helderberg limestone	40
Niagara limestone	640
Clinton (?) limestone	60
Hudson River and Utica	420
Trenton limestone	427
	2,027

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 260.

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Mishawaka.—Mishawaka lies on the gravel terrace above St. Joseph River, about 4 miles east of South Bend. The waterworks are owned by the city, and the supply taken from St. Joseph River is pumped by direct pressure into 17 miles of mains and 1,550 service taps. About two-thirds of the people use this water and require an average of 2,000,000 gallons per day.

The river water is very badly polluted, and few people use it for drinking. It receives all the sewage from Elkhart, Goshen, and other towns, besides much local pollution, and in its raw state is unfit for a city supply. The water could be greatly improved by the installation of a filter system such as is used at Indianapolis, Anderson, and other cities in this State.

There has been some discussion in Mishawaka as to the possibility of obtaining an artesian water supply such as is used in South Bend. Independent investigations of the underground water resources of this city were undertaken in 1906 by George C. Matson, of this Survey, and by the writer, and the same conclusions were reached by both. It is apparent that the coarse gravel bed which furnishes the water at South Bend becomes more and more sandy to the east, and beneath the terrace south of Mishawaka it is replaced by fine sand. The water in this sand is under sufficient artesian pressure to carry it within 15 or 20 feet of the surface, but the fineness of the material prevents its ready flow into the well, and the yield of wells in it will be small.

A well which was drilled at the brewery of Kamm & Schellinger in 1906 reached a depth of 723 feet without getting a good water supply. Some sulphur water was obtained near the bottom of the well, but this was not satisfactory and the well was abandoned. The following materials were penetrated:

Section of drilled well at Kamm & Schellinger brewery, Mishawaka.

	Feet.
Sand, gravel, and clay; little water, but some at 125 feet	130
Blue shale; no water	240
Limestone; some sulphur water near bottom	353
	723

This company also drilled three test wells in the marsh one-half mile south of the brewery, but obtained little water. South and east of this town deep wells have been more successful. At the Dodge Manufacturing Company's plant there are five 6-inch wells, 45 to 60 feet deep, in a coarse gravel, which will yield 250 gallons per minute each. At the National Veneer Products Company's factory a single 6-inch well, 67 feet deep, will yield 500 gallons per minute. Analyses of both of these waters are Nos. 2 and 4 in the table on page 213.

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The best available source of supply for Mishawaka, therefore, is from wells drilled south and east of the town. A large tract of land could be obtained around the wells, and proper precautions taken to prevent contamination of the water from sewage. If enough wells were drilled and they were placed as far apart as possible, there is every reason to believe that an adequate and desirable supply of well water could be obtained for the city.

The private wells of Mishawaka, from which the entire supply of drinking water is drawn, are almost all driven wells, which range in depth from 10 to 90 feet, and most of which end in gravel at a depth of 40 feet. The water rises within 2 to 20 feet of the surface. The wells furnish a somewhat safer and certainly a more palatable water than that furnished by the city system. The shallow wells, however, are almost certain to be more or less polluted when located in a thickly settled district. There is no protective bed of clay above the water-bearing gravel, and objectionable liquid matter of all kinds enters the ground in large quantities and becomes a part of the underground water supply. The deeper-driven wells are much safer than the shallow ones.

Walkerton.—The town of Walkerton built a public water system in 1897, and four drilled wells, 30 feet deep and 6 inches in diameter, furnish the supply. The wells enter gravel at 15 feet, and the yield is sufficient for present demands. A steam pump forces the water to a tank, which is 105 feet above ground and holds 1,700 barrels. Ordinarily the water is distributed by gravity, but in case of fire a higher pressure is obtained by pumping directly into the mains. There are about 3 miles of 6 and 4 inch mains and about half the people use the water, of which 3,000 barrels per day is pumped.

For private supplies driven wells are used in Walkerton to the exclusion of other types. These range in depth from 18 to 45 feet, the most common depth being 30 feet. The wells are in gravel, and the water stands at 15 to 25 feet below the surface. The waters are abundant, but all sewage of the town goes into the ground and the shallow wells are naturally the most easily polluted. It can be said that, in a general way, the deeper a well is the less likely it is to receive sewage from above. There are no impervious clay beds to protect the upper gravel waters.

New Carlisle.—The New Carlisle public water supply is owned by the town, and the water is taken from four drilled wells 118 feet deep and 5 inches in diameter. The town lies on the slopes of a moraine ridge and on the edge of the alluvial plain below, and the wells are near the base of the moraine slope. They penetrate to a gravel bed below blue clay and obtain abundant water of fine quality. A shallow dug well, 20 feet in diameter and 29 feet deep,

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has been built for use in emergencies, but the deep wells have so far supplied enough water for all purposes. The water is pumped to a tank located 85 feet above the pumps and holding 33,000 gallons, and is distributed by gravity to 2¾ miles of mains. Almost every family south of the railroad uses this water, though no mains have been laid north of it. Analyses of the city water are Nos. 5 and 6 in the table on page 213.

The few private wells in town, almost all of which are in the gravel plain north of the railroad, are of the driven type, and 20 feet is a usual depth. The water is from gravel and is plentiful, but because of the openness of the gravels and the abundance of private cesspools and other possible sources of contamination the sanitary conditions are unsafe.

North Liberty.—North Liberty has no public supply. The town lies on an alluvial plain, and each family owns a driven well, usually from 35 to 60 feet in depth, in which the water stands within 12 to 15 feet of the surface. The wells enter a gravel bed, and overlying clay beds are thin or altogether wanting. The supply is plentiful, and the deeper wells are good, especially when clay is penetrated above the water-bearing bed. Otherwise sewage is likely to enter, and the shallow wells in this town are not safe.

Other communities.—The following table contains a list of other villages in St. Joseph County, with particulars regarding their water supply:

Other village supplies in St. Joseph County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Crumstown	100	Wells, driven	10	25	20	133	6–10	Gravel.
Granger	67	do	25	50	28	.....	25	Do.
Hamilton	.....	do	10	30	18	.....	.....	Gravel and sand.
Lakeville	350	do	30	85	50	.....	10–20	Gravel.
Lydick	100	do	20	75	40	.....	.....	Do.
Osceola	177	do	25	30	27	.....	22	Do.
Polan Town	.....	do	10	22	18	.....	6	Do.
Terre Coupe	.....	do	10	30	18	.....	.....	Gravel and sand.
Walnut Grove	.....	do	90	113	100	.....	80	Gravel.
Woodland	90	Wells, driven and dug.	20	110	100	.....	.....	Do.
Wyatt	170	do	18	120	100	.....	4–20	Do.

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TYPICAL WELLS AND ANALYSES.

The two following tables give detailed information regarding typical wells in St. Joseph County, and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in St. Joseph County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Analysis No.
			Feet.		*Inches.*	*Feet.*	*Feet.*		*Ft.*	
1	Alexander Moore	Lakeville.....	50	Driven..	2	50	−15	Gravel..	....	1
2	Dodge Manufacturing Co.	Mishawaka....	45–60	.....	6	45–60	−10	...do.....	....	2
3	Kamm & Schellinger.	.....do.....	723	Drilled..	6	125	.....	Sand....	125	.....
4	Public well.....	Mishawaka, corner Main and Second streets.	35	Driven..	1½	35	.....	Gravel..	.....	3
5	Mishawaka Woolen Manufacturing Co.	Mishawaka....	176	Drilled..	6	.....	.....	.....	49	.....
6	National Veneer Products Co.	.....do.....	67	Driven..	6	55	− 3	Gravel..	.....	4
7	Public supply...	New Carlisle..	118	Drilled..	5	118	−28	...do.....	....	5,6
8	Robert Jimison.	North Liberty	38	Driven..	1½	38	−12	...do.....	....	7
9	Notre Dame University.	Notre Dame..	150	Drilled..	8	140	−25	...do.....	....	8
10	St. Mary's Academy.	.....do.....	100	...do.....	8,6	100	−15 to +3	...do.....	....	.....
11	L. S. Crull.....	Osceola.....	27	Driven..	1½	25	−22	...do.....	....	9
12	Public supply...	South Bend (central station).	112–116	Drilled..	4–10	112	+ 2	...do.....	....	17
13	Do.....	South Bend (north station).	87	...do.....	6–10	85	+ 8	...do.....	....	18
14	Singer Manufacturing Co.	South Bend...	40–100	...do.....	4	40–100	−12	...do.....	....	14
15	Indiana & Michigan Electric Co.	.....do.....	112	...do.....	8	112	+2 to −2	...do.....	....	16
16	Oliver Chilled Plow Works.	.....do.....	30	Dug.....	.....	30	− 9½	...do.....	.....	15
17	Studebaker Bros	.....do.....	90	Drilled..	10	90	.....	...do.....	.....	.....
18	Public supply...	Walkerton....	30	...do.....	6	.....	−15	...do.....	....	20, 21
19	J. H. Lydick....	Walnut Grove	113	Driven..	2	113	−80	...do.....	....	.....

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Mineral analyses of waters in St. Joseph County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Alexander Moore	Lakeville	Driven well, 50 ft. by 2 in.	H. E. Barnard	1907	Gravel		0.03		43	36			0.0	307	48	3.0	0.10	0.001	2	364	1
2	Dodge Manufacturing Co.	Mishawaka	Driven wells, 45 to 60 ft. by 6 in.	?		do	14	2.6		133	75	7.1		184		565	8.5					2
3	Public well		Main and Second streets, Mishawaka.	Driven well, 35 ft. by 1¼ in.	H. E. Barnard	1907	do		.20		152	44			.0	317	238	39	4	.001	2	794	4
4	National Veneer Products Co.	Mishawaka	Driven well, 67 ft. by 6 in.	do		1907	do		.01		71	76			.0	238	97	4.0	1.20	.001	9	294	6
5	City supply	New Carlisle	Drilled well, 118 ft. by 5 in.	Lake Shore and Michigan Southern R. R.	Sept., 1905	do				68	23	2.3		146		23	3.5					7
6	do	do	Drilled well, 118 ft. by 5 in.	H. E. Barnard	1907	do		.4		61	25			.0	273	41	2	.01	.001	9	326	7
7	Robert Jimison	North Liberty	Driven well, 38 ft. by 1¼ in.	do		1907	do				69	27			.0	289	112	36	.01	.001	2	462	8
8	Notre Dame University.	Notre Dame	Drilled well, 150 ft. by 8 in.	do		1907	do		.0		72	26			.0	243	30	4	.00	.001	2	236	9
9	L. S. Crull	Osceola	Driven well, 27 ft. by 1¼ in.	do		1907	do		.10		89	24			.0	213	70	43	1.0	.001	0	450	11
10	Lake Shore and Michigan Southern R. R.	South Bend	Well, 32 ft. by 20 ft.	Lake Shore and Michigan Southern R. R.	May, 1907	do				87	27	16		158		40	14	44				
11	Chicago, Indiana and Southern R. R.	do	Well, 25 ft. by 3 in.	do		do				159	58	37		135		399	57	.0				
12	City supply	do	Drilled wells, 87–116 ft. by 6 in.	do	Jan., 1905	do				68	23	6.3		138		32	9.7	Tr.				
13	Studebaker Bros	do	Well 35 ft. by 20 ft.	do	Dec., 1903	do		1.0		71	25	4.2		144		35	7.8	9.8				
14	Singer Manufacturing Co.	do	Open well, 35 ft.	Dearborn Chemical Co.		do	17	6.5		109	33	33		213		96	18				532	14
15	Oliver Plow Company	do	Open well, 30 ft. by 30 ft.	H. E. Barnard	1907	do		.0		76	28			.0	247	39	24	1.5	.001	0	372	16
16	Indiana and Michigan Electric Co.	do	Drilled well, 112 ft. by 8 in.	do	1907	do		.0		57	34			.0	218	10	7	.0	.001	4	270	15

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Mineral analyses of waters in St. Joseph County—Continued.

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
17	City supply (central station).	South Bend	Drilled wells, 112 to 116 ft.	Chase Palmer	Oct., 1907	Gravel	13	0.4	....	88	29	16		0.0	204	78	18	3.2	....	....	405	12
18	City supply (north station).	do	Drilled wells, 87 ft.	do	do	do	14	3.8	....	45	22	7.7		6.0	210	25	3.2	0.0	....	....	242	13
19	D. M. Barton	Terre Coupe	Well, 14 ft. by 1¼ in.	Lake Shore and Michigan Southern R. R.	Sept., 1905	....	....	....	....	48	12	3.2		....	....	....	5.0	....	....	....	....	....
20	Public supply	Walkerton	Drilled wells, 30–40 ft. by 6 in.	do	Feb., 1904	Gravel	....	1.0	....	95	26	43		....	139	....	72	67	47	....	....	18
21	do	do	do	H. E. Barnard	1907	do	....	....	....	89	30	....		.0	254	73	19	4	.0	2	612	16

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TIPTON COUNTY.

SURFACE FEATURES AND DRAINAGE.

Tipton County lies in the middle north-south tier of counties in the area under discussion and in the third tier from the south edge. Tipton, the county seat, is 36 miles north of Indianapolis. The county, which is rectangular in outline, is 20 miles long and 13 wide, and has an area of 260 square miles. The population in 1900 was 19,116, or 73 inhabitants to the square mile.

The county, a typical upland area, lies on the divide between White and Wabash rivers, although the watershed is a flat, featureless plain. About three-fourths of the surface lies between 850 and 900 feet above sea level. Only the valley of Duck Creek, in the southwest corner, falls below 850 feet, and in the southwest edge the surface rises somewhat above 900 feet, the total range in elevation being not more than 75 feet.

All of the surface except a small area bordering on Boone and Hamilton counties consists of a flat plain with an entire absence of hills or of deep valleys. In some places, however, it shows slight wavelike undulations, with the crests only 5 or 6 feet above the troughs. The morainic areas (Pl. I) have somewhat greater relief, with low knolls and depressions and scattered bowlders, but even there the crests of knolls are not many feet above the plain.

Tipton County includes a portion of the divide between the White River and the Wabash drainage systems. Cicero Creek, the most important of the tributaries of the White, drains the south-central and southwest portions, and at Atlanta lies 20 to 30 feet below the general level and has a narrow flood plain, but the valley becomes shallower to the north and west until the creek is only a few feet below the plain. Polliwog Creek, another tributary of White River, drains the southeast corner of the county.

North of Tipton the drainage belongs to the Wabash system. Most of the surface water is carried northeast into Howard County by Turkey and Mud creeks, tributaries of Wild Cat Creek, which in turn flows westward into Wabash River. All the valleys of the county are shallow and narrow.

Although the surface everywhere is flat, the drainage is well developed and there are no lakes and marshes. Still, in the districts where the slope is very slight, it has been found advisable to assist the natural drainage by ditches and by underground tilling. As a result, the land is nowhere too wet to permit cultivation.

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GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

Alluvial deposits are of as little extent here as in any other county in the area. They occur only as narrow and shallow flood-plain deposits along the larger streams, and since only the headwaters of even these larger streams are found in the county, it follows that there has been but little stream deposition and that the alluvium is generally unimportant as a source of water. The only valley in which the stream deposits have been penetrated by many wells is that of Cicero Creek, where some driven wells have found plenty of water at shallow depths in the open gravels along the valley floor.

The moraines of the county are all at its western edge. The larger area (Pl. I) is the north end of the long, low ridge that extends northward from the vicinity of Indianapolis. It is here not a very important topographic feature, but has a little more relief and is slightly more rolling than the till plain. There is also a small area of moraine that lies mostly in Howard County but extends into the extreme northwest corner of Tipton County. It is of the same general topographic character as that farther south.

For a long time shallow dug wells only were used to obtain water from the moraine areas, and these were supplied by slow seepage from the clay beds. Of late years the tide of public sentiment has turned strongly toward deep-driven or drilled wells, which are gradually replacing open wells. Many of them penetrate 100 to 200 feet of surface materials, and waters are almost everywhere obtained from layers of gravel interbedded with the clayey drift.

The till occupies the surface over a large proportion of the county and varies in thickness from 40 to 75 feet along the north and east edge to 200 or 300 feet at the south and west edges. The material is similar to that of the till wherever found in this area. Dug wells still predominate in the till, especially in the places where it is exceptionally thick, and many receive their entire supply from the close-grained clay. Such supplies are unsatisfactory, both in regard to quantity and quality, and the proportion of drilled wells is increasing. If the drilled wells fail to find sufficient water in the till they may be continued into the limestone, in which plentiful waters of good quality are to be found.

CONSOLIDATED MATERIALS.

As shown on Plate III, rocks of two periods underlie the surface deposits of Tipton County. The Silurian outcrops are all limestones and consist of the "Niagara" formation and the Kokomo limestone ("water lime"). Above them, and outcropping in the west edge of the county, are the lower Devonian beds. The beds all dip at low angles to the west and have been worn away by erosion to give the

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present distribution of outcrops below the drift. No rocks appear at the surface in this county.

As stated above, the Kokomo and "Niagara" beds are limestones, the former somewhat less massive than the latter. The Silurian limestones have been penetrated by wells at a number of points at Tipton and eastward. All of these rock wells show large quantities of water, and no record was found of wells which failed to get plenty of water when the rock was entered.

The Devonian limestones occur only in the area of very heavy drift and have been little exploited for their water. Deep gas borings have found good supplies, but these go into the Silurian as well as the Devonian rocks. It is probable, however, that the Devonian limestones are water bearing here as well as in other places where they have been tested, and wells of sufficient depth should be successful in these rocks.

ARTESIAN AREAS.

In contrast to the numerous artesian areas in the counties to the north and south, there are only two areas in Tipton County in which flowing wells are known to occur. This is explained by the position of the county on a high level plain and by the shallowness of the stream valleys. The head of the flowing waters in the neighboring counties is rarely more than 2 or 3 feet above the surface, even in the deeper valleys, and the absence of deep valleys in this county leaves few areas where the surface is below the level to which the artesian waters will rise.

In the valley of Cicero Creek near Tipton and to the south there are a number of flowing wells. (Pl. IV, No. 77.) All are old gas wells which are cased down to rock, so that the flowing waters must come from the Kokomo limestone ("water lime") or the "Niagara" formation. The flows are all small, and some wells which once flowed have now failed. The head of the water is but little above the surface, and seems gradually to be decreasing.

Flowing wells occur along the valley of Mud Creek within a few miles of Sharpsville. (Pl. IV, No. 78.) All are from old gas borings, and the water comes from the Silurian limestones. The strongest of these, on the farm of Mrs. Hannah Davenport, flows in a 1¼-inch stream.

CITY AND VILLAGE SUPPLIES.

Tipton.—The Tipton waterworks are the property of the city, and the supply is drawn from fifteen wells, of which five are gravel wells 68 to 114 feet deep. The water-bearing gravels are well protected from pollution from above by a heavy coating of impervious till. The rock wells, 10 in number, are 8 inches in diameter, and the gravel wells 4 and 6 inches. The water from the wells is forced by air lift

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to an underground cistern, and from this is pumped by direct pressure into the mains. There are 13 miles of mains, 4 to 12 inches in diameter, and 900 consumers are supplied. The daily consumption of water ranges from 300,000 to 400,000 gallons.

Many families in Tipton are still supplied from private wells, nearly all of which are driven into gravel, which is found at 30 to 60 feet below the surface. A common depth for them is 55 feet. The gravel waters are plentiful, and the deeper wells yield an abundance of pure and wholesome water. There are a few water wells that enter the limestone, which here lies 165 feet below the surface. Analyses of these waters are Nos. 1 to 8 in the table on page 220.

Windfall.—Windfall has no public water supply. Each family owns a private well and the town relies upon these wells for its water. There are many dug wells which are sunk 20 to 30 feet into the till, and these are certain to be more or less contaminated, as there is no sewerage system in the town and the open privy vaults are as numerous as the wells. All the liquid sewage enters the ground and some of it ultimately finds its way to the open wells and becomes mixed with the water which the people drink. The objectionable features of the dug wells are avoided by deep drilled or driven wells, which go through clayey till before entering water-bearing gravels or limestone. The till acts as a covering to prevent pollution of the deeper waters by organic matter from above. In Windfall the limestone is reached at a depth of 60 feet, and the pure and abundant rock waters furnish the best well supplies.

Sharpsville.—Sharpsville lies on the till plain near the shallow valley of Mud Creek. It has no public waterworks. The private wells are dug, drilled, or driven, and range in depth from 12 to 100 feet. The shallow dug wells in the clayey till are dangerous for the same reasons as those given for the dug wells at Windfall, and they should be abandoned as rapidly as possible. Driven wells, to be safe, should be sunk through a considerable depth of clay to keep out drainage from the surface. The rock wells furnish a fine quality of water and give the largest supplies. Limestone is entered at depths of 68 to 80 feet, and no wells in this rock have been failures.

Kempton.—The town of Kempton is situated at the west edge of the county on the border of a region of low moraine. The limestone is here 265 feet below the surface and its depth has prevented the utilization of limestone waters as a source of supply for the wells of the town, which are all driven or drilled, and enter gravel beneath pebbly clay. Most of them reach a gravel bed at a depth of about 34 feet. The record of a typical well of this sort is No. 5 in the table on page 219. Other wells enter gravel at 80 feet, and a still deeper gravel bed has been reached at a depth of 200 feet. The coating of till above even the first gravel protects the waters, and all the wells are good.

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Other communities.—The following table gives a list of other villages in Tipton County, with particulars regarding their water supply:

Other village supplies in Tipton County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Curtisville	123	Wells, dug and drilled.	20	90	25	90	15	Gravel and lime stone.
Ekin	100	Wells, driven and drilled.	20	60	25	240	8	Gravel.
Goldsmith	227	Wells, dug and drilled.	15	120	80	.....	.....	Do.
Groomsville	.....	Wells, drilled	25	50	40	120	.....	Do.
Hobbs	222	Wells, dug and drilled.	13	65	.....	180	10	Do.
Jackson	72	Wells, dug and driven.	18	160	22	90	10	Gravel and limestone.
Nevada	70	Wells, dug and drilled.	12	130	80	40–50	8–15	Do.
New Lancaster	100	.....do	20	60	50	50	8	Limestone and gravel.
Normanda	114	Wells, drilled and dug.	12	280	175	300	.....	Gravel.
Petersburg	.....	.....do	20	125	100	190	.....	Do.

TYPICAL WELLS AND ANALYSES.

The two following tables give detailed information regarding typical wells in Tipton County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in Tipton County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head below surface.	Water-bearing materials.	Depth to rock.	Analysis No.
			Feet.		*In.*	*Feet.*	*Feet.*		*Ft.*	
1	Schoolhouse	Atlanta	120	Drilled	4	120	.....	Gravel	.....	....
2	Lewis Land	Curtisville	80	...do	5	80	15	.....do	.....	....
3	R. B. Barr	1½ miles north of Goldsmith.	171	...do	2	171	11	.....do	.....	....
4	Sherman Hobbs	Hobbs	68	...do	4	68	10	.....do	.....	....
5	Fred Spencer	Kempton	33	Driven	1¼	33	15	.....do	.....	....
6	Lenley Coats	Nevada	132	Drilled	4	132	14	Limestone	70	....
7	Public well	Sharpsville	84	...do	4	82	8	.....do	68	....
8	Mike Hoffman	.....do	105	...do	4	.....	7	.....do	73	....
9	Carl Harper	½ mile south of Sharpsville.	122	...do	4	120	.....	.....do	70	....
10	City supply	Tipton	280	...do	6	275	15	.....do	139	1
11	.....do	.....do	62	...do	8	62	.....	Gravel	.....	2
12	J. N. Russell	.....do	212	...do	6	200	6–15	Limestone	120	....
13	Public well	Windfall	.....	...do	2	.....	.....	.....do	60	9
14	Windfall Canning Co.	.....do	217	...do	4	.....	.....	.....do	60	....

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Mineral analyses of waters in Tipton County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	City waterworks	Tipton	Drilled well, 280 ft.	R. B. Dole	1907	Limestone	25	1.7		73	15	31		0.0	411	1.3	5.4	4.2			350	10
2	Do	do	Drilled well, 62 ft.	do	1907	Gravel	26	4.3		76	28	20		.0	402	4.4	7.8	4.0			349	11
3	Lake Erie and Western Railroad.	do	Well, 184 ft.	Lake Erie and Western Railroad.	Nov., 1903			9.8		88	25	24		216		6.8	5.6	.0				
4	Do	do	Well, 225 ft.	do	Aug., 1904					69	29	23		202			6.1	.0				
5	Do	do	Well, 56 ft.	do	do					93	25	28		210		32	7.3	.0				
6	Do	do	Well, 168 ft.	do	Sept., 1903			2.0		70	27	23		195		1.0	6.7	.0				
7	A. H. Pence	do	Well	H. E. Barnard	Oct. 1907			.6		71	25			.0	348	0.0	8.0	.30	0.001	0.0	372	
8	A. W. Bowers	do	do	do	do			.6		19	30			.0	403	21	5.0	.40	.000	9	442	
9	Public well	Windfall	do	do	do	Limestone		1.0		83	7.6			.0	400	51	20	.50	.000	0	464	13

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WABASH COUNTY.

SURFACE FEATURES AND DRAINAGE.

Wabash County is situated on the east edge of the area treated in this report and half way between its north and south borders. The county is 27 miles long and 16 wide, and is regular in outline with the exception of a notch in the northeast corner formed by the corner of Whitley County. It has an area of 418 square miles and in 1900 the population was 28,235, or 68 to the square mile. Wabash, the county seat, lies 70 miles north and 18 miles east of Indianapolis.

The county is a broad, rather level plateau, across which Wabash River has cut a deep, broad valley medially from east to west. Two of its principal tributaries have cut valleys diagonally across the county, Eel River from the northeast and Mississinewa River from the southeast. The upland surface is a till plain, overlain in part by morainal deposits. Northwest of Eel River is an area of moraine, and east of the Wabash is another north and south moraine belt (Pl. I). These moraines occupy the highest portions of the surface. The extreme northwest corner reaches an elevation of 900 feet above tide, and the surface of the Mississinewa moraine is generally between 800 and 850 feet in elevation. The lowest point in the Wabash Valley, at the west edge of the county, is about 665 feet above sea level, giving a total range in elevation of about 235 feet.

Wabash River and its tributaries receive all the drainage, its valley being about 100 feet below the surface of the till plain and 150 feet or more lower than the crest of the Mississinewa moraine, through which it has cut its way. The valley is less than 1 mile wide above Wabash, but becomes gradually wider toward the west, and is cut in part into the surface deposits, and in part into the "Niagara" limestone.

Mississinewa River enters from Grant County and crosses the west border to join the Wabash above Peru. At Redbridge its valley is about 100 feet deep and is cut through the surface deposits to the rock, so that occasional outcrops of limestone show at the surface. Its drainage basin includes only a narrow belt at the south edge of the county.

Eel River, crossing the northwest corner of the county, follows roughly the southeast border of a great moraine, and with its tributaries drains nearly half of the surface. The stream valley is not more than 50 feet below the level of the till plain to the south, but the ridgelike crest of the moraine to the northwest reaches heights of nearly 200 feet above the river.

Lakes are found only in the morainic region northwest of Eel River and are of the same origin as those farther north, in Kosciusko County. They occupy basins in the irregular depressions of the moraine surface, which the agencies of erosion have so far failed to

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drain or fill. The Mississinewa moraine, while of greater area here than in Grant County, is of a more even character and lacks depressions in which the surface waters can collect. There are no marshes worthy of note.

GEOLOGY AND GROUND WATER.

UNCONSOLIDATED MATERIALS.

The only important alluvial deposits, along the bottom of the Wabash Valley, average less than a mile in width, though they are somewhat wider locally. Their thickness varies from place to place, but at Wabash, where they have been most often penetrated, they range up to 60 feet in thickness. Other areas of much smaller extent occur along the valley floors of Eel and Mississinewa rivers, where flood-plain deposits of gravel and sand are of local importance as water bearers. All the valley deposits are found to carry abundant waters, which are easily and cheaply obtained and which rise in the wells nearly to the surface. The water is well adapted for boiler and other industrial uses. For domestic purposes the shallow gravel wells should be avoided unless they are located in the country and well removed from dwellings, outhouses, or barns. The porous nature of the beds permits any sewage at the surface to penetrate readily into the ground, and in the absence of impervious clay beds above the water-bearing gravel the chances of pollution are many.

The distribution of the moraines of Wabash County is shown on Plate I. That area which lies northwest of Eel River is of strong morainic topography with irregular knolls, ridges, and undrained kettles, with many of the larger depressions occupied by lakes. The morainic material is unusually thick, doubtless 100 to 200 feet in the higher portions. The Mississinewa moraine stretches to the northeast and southeast of Wabash River east of Wabash. Its relief is much less than that of the heavy moraine farther northwest, and although the highest points of its surface stand scarcely 50 feet above the bordering till plain, the topography is distinctive and in sharp contrast to the level till-plain surface. There are no large lakes in its depressions.

The underground waters of the moraines must be obtained from the till or from the inclosed gravel or sand beds, and dug wells have been most commonly used to secure supplies from the clayey portions of the moraine. If gravel beds are encountered the supply is more abundant. Within the past ten years it has become generally known that drilled or driven wells are almost certain to strike gravel beds at depths of less than 100 feet, and almost all new wells are of one of these types, the water obtained being more plentiful and much safer than that obtained from dug wells.

Till plains occupy about two-thirds of the surface of Wabash County (Pl. I). The depth of the drift varies from a thin edge at

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points along the sides of the Wabash and Mississinewa valleys to 200, 300, and even 400 feet in the thickest portions. The surface deposits south of the Wabash are not generally of exceptional thickness, as wells commonly enter limestone at less than 100 feet. The rock surface is irregular, however, and contains deep drift-filled valleys. A boring at La Fontaine penetrated 400 feet of drift, and this old valley has been traced southeast through Grant County and beyond. Its extension northwest of La Fontaine is reported by a well driller, but can as yet be mapped only approximately. North of the Wabash the rock surface dips northward, and at North Manchester in the Eel River valley the drift is 274 feet thick. It is probable that this material is 400 feet thick in the moraine to the northwest. The compact till supplies water by seepage to a large number of dug wells, although many dug wells also enter gravel beds below till at depths of 20 to 40 feet and obtain an abundant supply. South of Wabash some drilled wells find good gravel beds in the till, but many have penetrated the underlying limestone before obtaining sufficient water. North of the Wabash, in the area of very thick drift, water-bearing gravels are found from 20 to 150 feet below the surface.

CONSOLIDATED MATERIALS.

All deep borings which have gone through the drift have next entered the "Niagara" limestone. This limestone, which outcrops at certain points along the deeper valleys, is very uniform in character throughout all the observed localities, and wells are universally successful if drilled deeply into it. South of Wabash River rock wells are common, and water can be obtained almost anywhere at depths of less than 100 feet. North of this river very few wells reach the limestone.

ARTESIAN AREAS.

The best known flowing well area in the county is that from which the city water supply of Wabash is obtained (Pl. IV, No. 79), in the valley of Treaty Creek, three-fourths of a mile from Wabash River and about 60 feet above it. There are now nine flowing wells in use and four more have been abandoned. At this point the drift is gravelly, and the artesian waters were obtained at depths of 40 to 60 feet and at 120 feet, and the nine wells yield, without pumping, about 1,500,000 gallons a day. The record of the materials penetrated by one of these wells is as follows:

Record of flowing well for city supply, Wabash.

	Feet.
Soil	2
Sand	3
Clay	33
White gravel (water-bearing)	60
Clay	19
Gravel (water-bearing)	8
	125

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Area 80 (Pl. IV) is in the valley of Treaty Creek about 3 miles above area 79, and has a single flowing well at White Institute. This well was drilled for gas about 1890, and still yields approximately 50 gallons of water per minute. The water is from the "Niagara" limestone and rises 3 feet above the surface.

Area 81 (Pl. IV) includes the valley of a small tributary of Mississinewa River at Somerset. The wells are all drilled into the "Niagara" limestone, and the artesian waters come from this formation. There are four flowing wells and they are dependent on the same source, as the later wells have reduced the flow of the earlier ones. The water has a temperature of 53½° F. The record of one of these wells is No. 12 in the table on page 228, and an analysis of the water is No. 10 in the table on page 229.

In the lowlands of the Eel River valley at North Manchester there are many flowing wells from 55 to 100 feet deep (Pl. IV, No. 82), the artesian waters being procured from gravel beds covered above by tough, impervious till. The water for the city supply is from flowing wells. The artesian pressure was formerly much stronger than it is now, but the wells have been left uncapped, and the continuous drainage of the gravel waters through many openings has greatly endangered this valuable supply. The wells are closely related to one another, and those situated on lower ground have seriously affected other wells higher up on the slope. Some which once flowed copiously have ceased to flow when other wells below have been put in, and neighborhood quarrels have arisen on this account. The remedy for this condition of affairs is obvious. A town ordinance should be passed requiring all flowing wells to be capped and faucets to be put in, so that only such water as is needed shall be drawn. This would restore the head to some extent and the flows of all the wells would be improved and the artesian head preserved. The present rapid diminution of the flows points to a total loss of the artesian head at no remote date.

In the Eel River valley near Liberty Mills there are about half a dozen flowing wells (Pl. IV, No. 83), all in gravel below till and 30 to 70 feet deep. The head is sufficient to raise the water 6 to 8 feet above the surface, and one well that flows about 35 gallons per minute is made to run a small water wheel, which pumps water throughout the dwelling house. The temperature of the wells that were measured was 52° F. The head seems to have been affected by the opening of a drainage ditch in the flat 3 miles east of the town.

Flowing wells are reported to occur at intervals along the Mississinewa Valley west of La Fontaine. All are rock wells, and belong to artesian area 27 (Pl. IV), described under Grant County (p. 120).

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CITY AND VILLAGE SUPPLIES.

Wabash.—The Wabash public supply is owned by the Wabash Electric Light and Water Works, a private corporation. The water is from nine flowing wells in the valley of Treaty Creek, described above as in artesian area 79. No water from Wabash River is used. From the wells the water flows by gravity to a covered reservoir at the pumping station, and from this it is forced to a standpipe on the hill, the pressure on the mains being maintained by gravity from the reservoir. There are 26 miles of mains from 6 to 12 inches in diameter, 1,790 taps are used to supply about 75 per cent of the people in Wabash, and 243 fire hydrants are installed for fire protection. About 1,300,000 gallons per day are pumped.

This is a most excellent water supply and is open to criticism only from the fact that sometimes the water becomes slightly turbid from the loosening of growths of iron-stained algæ, which accumulate at the well mouths and in the mains. This trouble could be lessened by proper care in removing this material from the boxes at the wells and by frequently flushing the mains.

Wabash is situated partly on a terrace above Wabash River and partly on the river bluff 70 feet above the terrace. In the lowlands the gravel deposits are in places as much as 60 feet thick and the water is abundant for drilled or driven wells. Many wells are owned by private individuals.

On the edge of the bluff the drift is only 10 to 20 feet thick, its depth increasing to the north, and the water table is very low near the edge of the bluff, so that almost everyone in the higher parts of town uses the public supply. A deep boring at Wabash gave the following section:[a]

Section of deep-well boring at Wabash.

	Feet.
Drift	28
Niagara limestone and shale	525
Hudson River and Utica	325
Trenton limestone	54
	932

North Manchester.—The North Manchester public water system is owned by the city, and the water is obtained from 12 flowing wells, described above as in artesian area 82. The record of the wells is No. 7 in the table on page 228. The water from six of the wells flows into a large cistern, and that from the other six is pumped into it. From the cistern the water is pumped to a standpipe 110 feet high and said to hold 160,000 gallons, and is distributed by gravity from

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 265.

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this standpipe. There are about 9 miles of mains and 250 service taps, and the people who use this supply (about one-third) require 130,000 gallons each day.

The privately owned wells of North Manchester are numerous, and are almost all driven or drilled. Fortunately most of the dug wells have been abandoned. The wells range in depth from 25 to 140 feet, with 65 feet as the common depth. The head of the water varies in different wells from several feet above the surface to 20 feet below it. All wells obtain water from gravel, and the supply from the deeper wells is good and pure. An analysis of this water is No. 8 in the table on page 229.

The geologic section in this town, as shown by a deep well drilled for gas, is as follows: [a]

Geologic section at North Manchester, as shown by deep-well record.

	Feet.
Drift	274
Niagara limestone and shale	300
Hudson River limestone and shale	250
Utica shale	306
Trenton limestone	50
	1,180

Roann.—Roann has no public waterworks, and privately owned driven and dug wells furnish the water supply. The wells are from 30 to 85 feet deep, the greater number being supplied by a gravel bed at 40 feet below the surface. The deeper gravel waters, where protected above by clays, are likely to be pure, but dug wells, especially in towns which have no sewage system, are very dangerous, as they are sure to become polluted to some extent. All dug wells in town should be filled up and replaced by deeper drilled or driven wells.

La Fontaine.—La Fontaine is supplied by privately owned wells, which are driven or drilled and are 14 to 100 feet deep. The water is found in gravel beds at various depths in the drift. The town is located over a great preglacial valley, which extends toward the southeast and northwest. Gas-well drillings have found as much as 442 feet of drift, while both to the east and west the limestone outcrops at the surface. This valley is a continuation of the same valley that J. A. Bownocker [b] has traced into Grant County from the southeast. The rock in this town is too far below the surface to have been used as a source for well supplies.

Laketon.—Laketon lies on a rolling till plain near Eel River, and the water supply is all obtained from private wells, there being no public supply. Most of the wells are drilled, but a few are dug, and all

[a] Sixteenth Ann. Rept. Indiana Dept. Geology and Nat. Hist., p. 253.
[b] Ohio State Acad. Sci., Special Paper No. 3, pp. 32–45.

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obtain water from gravel, no well here having penetrated to rock. The wells are from 14 to 65 feet deep, the greatest number entering gravel at 35 feet below the surface. The water generally rises within 10 feet of the well mouth. There are no springs of importance in the neighborhood.

Other communities.—The following table contains a list of other villages in Wabash County, with particulars regarding their water supply:

Other village supplies in Wabash County.

Town.	Population (1900).	Source.	Depth of wells.			Depth to rock.	Head below surface.	Character of water beds.
			Least.	Greatest.	Common.			
			Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Dora	102	Wells, driven and drilled; springs.	30	120	80	0–90	.....	Limestone and gravel.
Lagro	456	Wells drilled	40	100	70	3+	10–30	Limestone.
Liberty Mills	.....	Wells, drilled, driven, and dug.	25	100	30	.....	25	Gravel and sand.
Lincolnville	275	.....do.....	20	170	25,70	60–70	10–30	Gravel and limestone.
Mailtrace	30	Wells, drilled and dug	20	185	140	.....	.....	Gravel.
New Holland	72	.....do.....	15	44	30	0–30	15–20	Gravel and limestone.
Redbridge	30	.....do.....	10	120	100	0–60	.....	Limestone and gravel.
Rich Valley	132	Wells, driven, drilled, and dug.	18	30	25	.....	.....	Sand and gravel.
Rose Hill	89	Wells, dug and drilled	12	125	80	.....	.....	Gravel.
Servia	288	Wells, drilled, driven, and dug.	20	100	40	.....	15	Do.
Somerset	320	Wells, dug and drilled	11	110	20	65	.....	Gravel and limestone.
Spiker	.....	Wells, drilled	70	90	80	.....	.....	Gravel.
Treaty	147	.....do.....	30	70	60	.....	.....	Do.
Urbana	239	Wells, drilled and dug	20	120	70	101	10–35	Gravel and limestone.
Vernon	.....	.....do.....	14	120	20	80	.....	Do.

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TYPICAL WELLS AND ANALYSES.

The two following tables contain detailed information regarding typical wells in Wabash County and analyses of their waters. The numbers in the last column of each table refer to identical wells in the other table.

Records of typical wells in Wabash County.

No.	Owner.	Location.	Depth.	Type.	Diameter.	Depth to water bed.	Head above (+) or below (−) surface.	Water-bearing materials.	Depth to rock.	Flow per minute.	Analysis.
			Feet.		*In.*	*Ft.*	*Ft.*		*Ft.*	*Galls.*	
1	Dr. R. L. Banister.	La Fontaine	38	Driven	1¼	.....	−20	Gravel	.....	.....	1
2	Public well	Lagro	72	Drilled	6	72	− 6	Limestone	6	.....	2
3	.....do	Laketon	37	...do	2	37	−16	Gravel	.....	.....	4
4	Wm. Iholtz	Liberty Mills	30	...do	2	.....	+ 6	.....do	.....	.....	.....
5	Edw. Rittenhouse	.....do	68	...do	2	65	+ 8	.....do	.....	35	5
6	E. A. Kanower	Mailtrace	132	...do	2	130	−40	.....do	.....	.....	.....
7	Public supply	North Manchester.	80–100	...do	2	.....	+ 3	.....do	.....	.....	7
8	Isaac Lowrey	.....do	55	...do	2	98	+ 3	.....do	.....	6	8
9	North Manchester Creamery.	.....do	75	...do	2	75	+ 5	.....do	.....	20	.....
10	Joseph Overman	Redbridge	125	...do	4	.....	−70	Limestone	60	.....	.....
11	Public well	Roann	40	Dug	.....	38	−35	Gravel	.....	.....	9
12	Jacob Drook	Somerset	120	Drilled	3½	120	+ 0	Limestone	60	.....	10
13	Geo. O. Miller	Urbana	131	...do	4	65	− 8	.....do	101	.....	12
14	Daniel E. Spiker	.....do	80	...do	2	80	.....	Gravel	.....	.....	11
15	Dr. H. Adee	Vernon	120	...do	2	.....	−13	Limestone	80	.....	.....
16	Wabash Electric Light and Water Works.	Wabash	45–65	...do	8,6	.....	+12	Gravel	.....	.....	15
17	.....do	.....do	390	...do	6	.....	+ 0	Limestone	100	.....	.....
18	.....do	.....do	126	...do	6	120	+20	Gravel	.....	325	14,16
19	Pioneer Hat Works	.....do	169	...do	6	.....	−50	Limestone	60	.....	.....
20	White Institute	4 miles SE. of Wabash.	900	...do	8	.....	+ 3	.....do	.....	50	.....

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Mineral analyses of waters in Wabash County.

[Parts per million.]

No.	Owner.	Location.	Source.	Analyst.	Date.	Material in which water occurs.	Silica (SiO_2).	Iron (Fe).	Aluminum (Al).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Nitrate radicle (NO_3).	Nitrite radicle (NO_2).	Color.	Total solids.	No. in record of wells.
1	Dr. R. L. Banister..	La Fontaine.	Driven well, 38 ft. by 1¼ in.	H. E. Barnard	Nov., 1907	Gravel.....	....	1.4	....	102	20	.....	.....	0.0	244	159	24	0.00	0.002	9	2086	1
2	Public well.....	Lagro.....	Drilled well, 72 ft. by 6 in.	.....do.....	1907	Limestone ..	....	.4	....	119	69	.....	.....	.0	359	178	54	1.5	.001	4	816	2
3	.....	Laketon.....	Round Lake.....	W. B. Landon	May, 1906	.....	2.1	1.9		72	19	15		114	....	92	5.3	.....	.....	.....	.....	.....
4	Public well.....	.....do.....	Drilled well, 37 ft. by 2 in.	H. E. Barnard	Sept., 1907	Gravel.....	....	.01	....	162	35	.....	.....	.0	346	70	59	2.00	.00	2	676	3
5	Edw. Rittenhouse.	Liberty Mills	Well, 68 ft. by 2 in....	.....do.....	.....do	.....	....	.6	....	86	34	.....	.....	.0	313	19	3	.001	.008	28	356	5
6	.....	North Manchester.	Eel River.....	Cleveland, Cincinnati, Chicago and St. Louis Ry.	.....	.....	11	12		50	14	24		92	....	41	6.1	.....	.....	.....	292	....
7	City supply.....	.....do.....	Drilled wells, 80 to 100 ft. by 2 in.	R. B. Dole....	Sept., 1907	Gravel.....	21	.94	....	64	25	11		.0	312	13	1.5	0.5	.....	.....	284	7
8	Isaac Lowrey.....	.....do.....	Drilled well, 55 ft. by 2 in.	H. E. Barnard	....do	.....do.....	....	.8	....	94	4	.....	.....	.0	262	48	1.6	.001	.001	32	390	8
9	Public well.....	Roann.....	Open well, 40 ft.....	.....do.....	....do	.....do.....	....	.4	....	146	37	.....	.....	.0	345	96	34	8.00	.001	2	626	11
10	Jacob Drook.....	Somerset....	Drilled well, 120 ft. by 3¼ in.	.....do.....	1907	Limestone ..	....	.8	....	96	35	.....	.....	.0	341	0	34	.05	.001	4	462	12
11	Daniel E. Spiker...	Urbana.....	Drilled well, 80 ft. by 2 in.	.....do.....	Sept., 1907	Gravel.....	....	.2	....	69	41	.....	.....	.0	324	77	3	1.00	.001	19	460	14
12	Geo. O. Miller.....	.....do.....	Drilled well, 131 ft. by 4 in.	.....do.....	....do	Limestone ..	....	.0	....	89	31	.....	.....	.0	284	87	10	.00	.00	4	466	13
13	Wabash Electric Light and Water Works.	Wabash.....	Well, 13 ft.....	Dearborn Drug & Chemical Co.	.....	.....	11	5.3	....	83	27	4.7	....	181	....	13	7.3	.....	.....	.....	340	....
14	City supply.....	.....do.....	Drilled well, 126 ft. by 6 in.	H. E. Barnard	1907	Gravel.....	....	1.2	....	78	30	.....	.....	.0	329	22	5	.00	.001	4	382	18
15	.....do.....	.....do.....	Wells, 45 to 390 feet....	Cleveland, Cincinnati, Chicago and St. Louis Ry.	.....	.....	19	3.1		147	42	10		224	....	162	19	.....	.....	.....	634	16
16	.....do.....	.....do.....	Drilled well, 126 ft. by 6 in.	R. B. Dole....	Sept., 1907	Gravel.....	22	.70	....	53	31	17		.0	278	25	3.8	0.4	.....	.....	286	18

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CHEMICAL CHARACTER OF THE WATERS OF NORTH-CENTRAL INDIANA.

By R. B. Dole.

INTRODUCTION.

Information regarding the characteristics of individual waters in north-central Indiana is of so local interest and can be so readily obtained from the tables of analyses in the main part of the report that it does not merit space here. The purpose of this paper is rather to suggest standards that may assist intelligent study of the analytical data and may show the broad general relations with respect to quality between the wells and other sources of supply in this and in other regions. The methods of testing the waters are, therefore, briefly outlined, the chief uses of water are reviewed, and the qualities peculiar to each class of waters are discussed. In conclusion some assays giving further information are presented.

METHODS OF ANALYSIS.

Many analyses quoted in the preceding pages were made by industrial chemists chiefly to determine the value of the waters as sources of railroad supply. Such estimates are usually made in accordance with accepted procedure for industrial work and the results are sufficiently accurate for most purposes. These analyses, originally stated in hypothetical combinations in grains per gallon, have been recomputed to ionic form in parts per million in order that they may be compared with analyses from other sources. Though it is probable that normal carbonates are actually present in only a few of these waters, it was impossible to determine this certainly from the hypothetical statements, and therefore it has been necessary to compute combined carbonic acid to the carbonate radicle (CO_3) in nearly all these analyses.

The analyses by Dole, Palmer, and Van Winkle were made in special laboratories of the United States Geological Survey in accordance with the methods outlined in Water-Supply Paper 236, pages 9 to 26, inclusive. The probable accuracy of the methods and their

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sources of error are discussed in the same publication. The samples of water for these tests were collected in 1-gallon glass-stoppered bottles supplied to the field force from the laboratories, and the waters were examined as soon as practicable after collection.

One-pint samples also were collected by the field men and shipped to Indianapolis, where Dr. H. E. Barnard, chief chemist of the Indiana state board of health, examined them for total solids, iron, calcium, magnesium, carbonates, bicarbonates, sulphates, nitrates, and chlorides. As only a small amount of water was available special procedures had to be used. One hundred cubic centimeters of the sample was titrated with fiftieth normal sulphuric acid in the presence of phenolphthalein indicator to estimate carbonates, after which methyl orange was added and titration with fiftieth normal sulphuric acid was continued until the end point indicated by methyl orange appeared, in order to determine the amount of bicarbonates. To the residue from the bicarbonate determination 5 cubic centimeters of a saturated solution of ammonium chloride was added with sufficient ammonia to make the solution alkaline. After the solution was heated to boiling 10 cubic centimeters of a saturated solution of ammonium oxalate was added and the solution was allowed to cool. The precipitate was removed by filtration, washed with hot water, ignited, and weighed as calcium oxide. To the filtrate from the determination of calcium 10 cubic centimeters of ammonia and 10 cubic centimeters of a saturated solution of sodium ammonium phosphate were added, after which the contents of the dish were stirred vigorously three or four minutes and then allowed to stand three hours. The precipitate removed by filtration was washed with ammonia water (1 to 3) and ignited slowly at first, but with gradually increasing temperature until a white ash was obtained, when the magnesium was weighed as magnesium pyrophosphate. For the determination of chlorine 10 cubic centimeters of the sample was titrated with a solution of silver nitrate containing 4.789 grams $AgNO_3$ in 1 liter of distilled water. For the determination of sulphates 100 cubic centimeters of the sample was acidified with hydrochloric acid, heated to boiling, and the sulphates precipitated with 10 cubic centimeters of a saturated solution of barium chloride. The precipitate, after being removed by filtration in hot solution, was washed with hot water, dried, ignited, and weighed as barium sulphate, from which the amount of the sulphate radicle (SO_4) was computed. For total solids 50 cubic centimeters of the sample was evaporated in a platinum dish on the water bath and the residue weighed. The residue from the determination of total solids was dissolved in 15 cubic centimeters of dilute hydrochloric acid, transferred to a beaker, 3 or 4 drops of nitric acid were added, and the solution was heated for ten minutes on the water bath. It was then

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transferred to a Nessler tube and 5 cubic centimeters of a 5 per cent solution of potassium sulphocyanide was added. The color developed was compared with that in iron standards prepared from ferrous ammonium sulphate. Nitrates were estimated in a 10 cubic centimeter sample by the phenol-sulphonic acid method.

Field assays made during a short field study of the quality of boiler waters in Wabash Valley are reported in a table at the end of this paper. They were performed in accordance with the methods outlined in Water-Supply Paper 151, and though only a few estimates were made for each water the information throws some additional light on the quality of the waters. The figures in the column headed "probable incrustants" are obtained by adding to bicarbonates computed to $CaCO_3$ the sulphates computed to $CaSO_4$ and finding the average between this sum and the figure representing total hardness, in accordance with the following formula. This computation is necessarily arbitrary and the result is only roughly approximate.

$$\text{Probable incrustants} = \frac{0.82\ HCO_3 + 1.42\ SO_4 + \text{total hardness.}}{2}$$

EXPRESSION OF ANALYTICAL RESULTS.

The results of the analyses in this paper are stated in parts per million, and though the amounts of water for examination were measured by volume the mineral content is usually so low that the figures may be considered to represent parts per million by weight. Simplicity of computations, avoidance of fractions, and certainty of the basic unit make this decimal system especially satisfactory for practical purposes. Expression of the results of water analyses in parts per million has been generally adopted by sanitary and research chemists and by many technical chemists, and the exclusive employment of this unit industrially is delayed only by more or less objectionable precedent.

For the convenience of those who may desire to transform the results to other forms of expression it may be stated that multiplying the number of parts per million by 0.058 gives the equivalent in grains per United States gallon of 231 cubic inches, multiplying it by 0.07 gives the equivalent in grains per imperial gallon, and multiplying it by 0.00833 gives the equivalent in pounds per thousand gallons.

The analytical methods commonly employed in the examination of water permit the estimation of the elements and radicles that are present; they also permit the determination of the total amount of mineral matter in solution and more or less approximate separation of the incrusting from the nonincrusting constituents. Besides these data, however, ordinary chemical tests give little knowledge regarding the chemical composition of mineral waters, and consequently

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the exact amounts of the different salts in solution are largely matter for conjecture. Though such salts as sodium chloride, potassium carbonate, and magnesium sulphate are probably present, they are not determined as such, and their exact amounts can not be computed from the analytical data. The ionic form of stating the analyses—that is, statement of the radicles present—has been adopted in this report because it gives fact and not opinion. The form is entirely practical and presents the actual results for the consideration and criticism of persons other than those making the tests.

STANDARDS FOR CLASSIFICATION.

MINERAL CONSTITUENTS OF WATER.

All natural waters contain, dissolved or suspended in them, more or less of all materials with which they have come in contact. Such materials are taken up in amounts determined principally by their chemical composition and physical structure, temperature and pressure, the duration of contact, and the condition of substances that have previously been incorporated in the water. To designate such suspended or dissolved matter as "impurities" is hardly correct, because they are introduced normally—in strict accordance with natural conditions and not necessarily by human agency. It has become customary, however, to call such substances impurities when they are detrimental or injurious in some proposed use of a water supply. For purposes of examination the substances that may be present are classified as suspended matter, such as particles of clay or leaves; dissolved matter, either of mineral or organic origin; microscopic animals or plants; and bacteria. The presence or absence of very small animals and plants likely to affect the quality of waters is determined by microscopic examination, and the chance of contracting disease by drinking the water is ascertained by bacteriological processes. The mineral substances in the well waters of north-central Indiana are the most important, however, and consideration is therefore given in the present study chiefly to the suspended and the dissolved mineral matter. The amount and nature of the mineral ingredients are most commonly determined by estimates of total suspended matter, total dissolved matter, total hardness, total alkalinity, silica, iron, aluminum, calcium, magnesium, sodium, potassium, carbonates, bicarbonates, sulphates, nitrates, chlorides, free carbonic acid, and free hydrogen sulphide. These estimates are measure of the materials most commonly present and most likely to affect the value of the waters. Articles describing the methods employed in making these estimates have already been cited under the heading "Methods of analysis" (p. 230).

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USES OF WATER.

In judging the value of a water from the data afforded by analysis it is necessary to consider the supply both in relation to the use to which it is to be put and in relation to other available supplies. Besides being used for drinking and for general domestic purposes, water is essential in steam making, paper making, starch manufacture, and many other industrial processes. The medicinal properties of the dissolved minerals are supposed to give many waters special significance. For each of these purposes the relative amounts of certain ingredients in a water determine its value and assist in its classification. For example, considerable iron in a water may be harmful in one industrial process and harmless in another. The value of a water for another process may be directly measurable by the amount of suspended matter present, the amount of dissolved matter not being significant. Furthermore, many waters that are considered of great medicinal value are unfit for boiler use.

To catalogue waters as good or bad, hard or soft, pure or impure, is indefinite and frequently misleading. Absolutely pure water (H_2O) does not exist in nature, and, as stated before, a water should not be called impure when it contains only substances derived by natural means from natural sources. The arithmetical values of terms ordinarily employed to describe the quality of water, like those of many other words, are variable and largely dependent on local usage. In New England, for instance, water to be considered soft must have much less than 100 parts per million of total hardness, and water containing 30 or 40 parts of sulphates would not be used. In northern Indiana, however, it would be difficult to find a well water with total hardness less than 100 parts per million, yet many well waters in that region are called soft, and waters containing 30 to 40 parts of sulphates are often used in boilers without occasioning much comment. This example illustrates the uncertain significance of general descriptive words in classifying waters and emphasizes the advisability of knowing the intended use of a water and the composition of other available supplies before pronouncing judgment on its quality.

WATER FOR DOMESTIC PURPOSES.

CONDITIONS IN NORTH-CENTRAL INDIANA.

The flat topography of north-central Indiana makes highland conserved supplies impossible, and the comparatively few meandering streams of this prairie land are often so turbid or so evidently polluted that the prospect of using them as sources of domestic supply without purification is not inviting. Consequently wells furnish most of the water for drinking and for general domestic purposes.

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Of 54 cities and villages having municipal supplies, 48 obtain all or part of their water from underground sources and 44 use well water exclusively. (See pp. 53–54.)

PHYSICAL QUALITIES.

To be entirely acceptable as a domestic supply, water should be free from suspended matter, color, and odor, and fairly cool when it reaches the consumer; it should be free from disease-bearing germs, and it should be low in dissolved mineral ingredients. The nearer a water approaches these conditions the more satisfactory it is for general use. Suspended mineral matter clogs pipes, valves, and faucets, and growths of microscopic plants suspended in water frequently cause stains in clothes and bad odors. The red or reddish-brown masses of suspended matter sometimes occurring in well waters of this region are usually growths of *Crenothrix*, which is described by Whipple[a] as a small filamentous plant having a gelatinous sheath colored by a deposit of ferric oxide. It grows especially in ground waters containing considerable iron, forming tufts or layers in water pipes and well casings and sometimes clogging them. Particles becoming detached escape through faucets, giving the water an unsightly appearance and causing rusty stains on clothes washed in the water. So far as is known, *Crenothrix* in drinking water does not cause disease. Color is usually due to dissolved vegetable matter and is a cause of serious objection only when it exceeds 20 or 30 parts per million. In general the well waters of this area are satisfactory in respect to suspended mineral matter and color. Sometimes finely divided material from quicksands enters driven wells, but such trouble is not nearly so serious here as in other parts of the country. A few of the waters, especially those containing iron, develop a turbidity of 10 to 30 parts per million on exposure to the air, due to precipitation of dissolved matter, and such a condition gives rise to an apparent though not a real color. Most of the color recorded in analyses of these well waters is due to this cause, and true colors are so low as to be insignificant. Odors may be caused by various conditions. An odor like that of rotten eggs, encountered in many waters in the oil belt, is due to free hydrogen sulphide (H_2S). Growths of microscopic organisms in tanks and water mains often have unpleasant odors that make the water objectionable.

BACTERIOLOGICAL QUALITIES.

Before a water is used for domestic purposes there should be reasonable certainty that it is free from disease-bearing organisms. Yet present bacteriological technique does not permit positive

[a] Whipple, G. C., The microscopy of drinking water, New York, 1899, p. 144.

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statement regarding the presence or absence of such organisms, and it is advisable, therefore, to guard supplies against all chances of infection. The disease germs most commonly carried by water are those of typhoid fever. The bacilli enter the supply from some spot infected by the discharges of a person sick with this disease, and, though the germs are comparatively short lived in water, they persist in fecal deposits for remarkable lengths of time and retain their power to infect water. Consequently, wells should be so located that their waters are guarded against the entrance of filth of any kind, either over the top or by infiltration, and pumps and piping in the system should also be protected. The types of rural water supplies with reference to pollution in a central-western section of the United States have been discussed by Kellerman and Whittaker.[a] Considered as to bacteriological purity, the well waters of north-central Indiana in general are good. Water from a carefully cased well over 20 or 30 feet deep is acceptable if the well is located after the exercise of reasonable judgment in regard to privies, cesspools, and other sources of pollution. Open dug wells and the pits often constructed as reservoirs around the tops of casings are frequently exposed to fecal contamination from above or through cracks in poorly built side walls. Care should be taken that the casings of deep wells do not become leaky near the surface of the ground so as to allow pollution to enter. As a matter of ordinary precaution the ground should be kept clean and water should not be allowed to become foul or stagnant near any well, no matter how deep it is. If shallow dug wells are necessary, they should be constructed with water-tight casings extending down into the well as far as practicable and also a short distance above ground. The floor, or curbing, should be water-tight, and pumps should be used in preference to buckets for raising the water. Every possible precaution should be taken to prevent feet scrapings and similar dirt from getting into the water by way of the top of the well. Underground water is not only less likely to become contaminated if protected from surface washings, air, and light, but it keeps better and is less likely to develop microscopic plants that give it a bad taste.

CHEMICAL QUALITIES.

Amounts of dissolved substances permissible in a domestic supply depend much on their nature. No more than traces of barium, copper, zinc, or lead should be present, because these substances are poisonous. The occurrence of these elements in measurable amounts in ordinary well waters is so rare that tests for them are not usually made. Any constituent present in sufficient amount to be clearly per-

[a] Kellerman, K. F. and Whittaker, H. A., Farm water supplies of Minnesota: Bull. Bur. Plant Industry No. 154, U. S. Dept. Agr., 1909.

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ceptible to the taste is objectionable. Two parts per million of iron is unpalatable to many people, and even this small amount can cause trouble by discoloring washbowls and tubs and by producing rusty stains on clothes. Tea or coffee can not be made satisfactorily with water containing much iron, because an inky black compound is formed. Four or five parts of hydrogen sulphide are unpleasant to the taste, and this dissolved gas is objectionable also because it corrodes well strainers and other metal fittings. Many well waters in this area contain so much free hydrogen sulphide that they are unfit for use. The amounts of silica and aluminum ordinarily present in well waters have no special significance in relation to domestic supply. The alkalies, sodium and potassium, are high in most Indiana waters in which chlorides are high.

Approximately 250 parts of chlorides make a water taste "salty," and much less than that amount causes corrosion. In regions where the chloride content runs as low as 5 or 10 parts in normal waters unaffected by animal pollution the amount of chlorides is frequently taken as a measure of contamination. But such practice in north-central Indiana is out of the question for two reasons: First, the normal chloride content in most of the well waters is so high that the small changes possibly caused by animal pollution are insignificant; second, wells near together and free from contamination may differ 200 or 300 per cent in their content of chlorides, owing to difference in the composition of the materials from which they draw their respective supplies. Therefore the establishment of isochlors, or lines of equal chlorine, in this area would be of no sanitary value whatever.

Calcium and magnesium are chiefly responsible for what is known as the hardness of water. This undesirable quality is indicated by increased soap consumption and by deposition on kettles of scale composed almost entirely of calcium, magnesium, carbonates, and sulphates. Calcium and magnesium unite with soap, forming insoluble curdy compounds with no cleansing value and preventing the formation of a lather until all of these two basic radicles has been precipitated. Hardness is measured by the soap-consuming capacity of a water expressed as an equivalent of calcium carbonate ($CaCO_3$), and it can be computed from the amounts of calcium and magnesium in a water or can be determined by actual testing with standard soap solution. If, as Whipple states,[a] 1 pound of ordinary soap will soften only about 24 gallons of water having a total hardness of 200 parts per million, it can readily be seen that housekeepers and owners of laundries in north-central Indiana are intimately concerned in the hardness of water, which ranges in this region from 150 to 500

[a] Whipple, G. C., The value of pure water, New York, 1907, p. 26.

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parts per million and does not in many samples fall below 200 parts. The use of soda ash (sodium carbonate) to "break" such waters, or to precipitate the calcium and magnesium, is common and effects saving in the cost of soap. Some large cities in other States have found it advisable to soften their public water supplies instead of leaving that task to the individual consumer.

WATER FOR BOILER USE.

IMPORTANCE OF MINERAL CONTENT.

The amount of mineral matter in the waters of north-central Indiana is so considerable that the selection of proper supplies for boiler use depends largely on the chemical composition of available waters, and the quantity of water required for locomotives by the network of railroads in this section is so enormous that its quality is a matter of high importance in industrial economy. The chief troubles in boiler-room practice caused by the mineral constituents of natural waters are formation of scale, corrosion, and priming.

FORMATION OF SCALE.

The most common trouble is formation of scale, or deposition of mineral matter within the boiler shell. When water is heated under pressure and concentrated by evaporation, as in a steam boiler, certain substances are thrown out of solution and solidify on the flues and crown sheets or within the tubes. These deposits cause increased fuel consumption because they are poor conductors of heat and increased cost of boiler repairs and attendance because they have to be removed. If the amount of scale is very great or if it is allowed to accumulate the boiler capacity is decreased and disastrous explosions are likely to take place. In two years the inspectors for one insurance company [a] found over 86,000 boilers, or nearly one-fifth of all those examined, to be defective on account of sediment, incrustation, and scale.

The importance of scale formation and of means of reducing or preventing it may be judged by considering the effect of a water such as is shown on page 265 by the average composition of the waters in the fresh-water limestones. If such water were used in a system without condensers under ordinary conditions it would form about 2.6 pounds of scale to 1,000 gallons of water; besides the increased fuel consumption and increased depreciation of the plant caused by this deposit, the scale itself in a 1,000-horsepower system would amount to a ton every seven working days, and this mass would have to be shoveled, scraped, and hammered from the inside of the boiler.

[a] The Locomotive (Hartford), new ser., vol. 21, 1900, p. 29; vol. 22, 1901, p. 21.

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In one boiler room in Indianapolis $160 a month has been saved in maintenance charges by treating the water supply.[a]

The scale or incrustation consists of the substances that are insoluble in the feed water or become so within the boiler under conditions of ordinary operation. It includes practically all the suspended matter, or mud; the silica, probably precipitated as silica (SiO_2); the iron and aluminum, appearing in the scale as oxides or hydrated oxides; the calcium, precipitated principally in the form of carbonate and sulphate; and the magnesium, found in the deposits principally as the oxide but partly as the carbonate. The scale conconstituted by these substances is therefore a mixture of compounds, which varies in amount, density, hardness, and composition with different conditions of water supply, steam pressure, type of boiler, and other circumstances. Calcium and magnesium are the principal basic substances in the scale, over 90 per cent of which usually is calcium, magnesium, carbonates, and sulphates. If much organic matter is present part of it is precipitated with the mineral scale, as the organic matter is decomposed by heat or by reaction with other substances. If magnesium and sulphates are comparatively low or if suspended matter is comparatively high the scale is soft and bulky and may be in the form of sludge that can be blown or washed from the boiler. On the other hand, a clear water relatively high in magnesium and sulphates may produce a hard, compact scale that is nearly as dense as porcelain, clings to the tubes, and offers great resistance to the transmission of heat. Therefore the value of a water for boiler use depends not only on the quantity of scale produced by it but also on the physical structure of the scale.

CORROSION.

Corrosion or "pitting" is caused chiefly by the solvent action of acids on the iron of the boiler. Free acids capable of dissolving iron occur in some natural waters, especially in the drainage from coal mines, which usually contains free sulphuric acid. Many ground waters contain free hydrogen sulphide, a gas that readily attacks boilers; dissolved oxygen and free carbon dioxide also are corrosive in their action. Organic matter is probably a source of acids, for it is well known that waters high in organic matter and low in calcium and magnesium are corrosive, though the exact nature and action of the organic bodies are not understood. Acids freed in the boiler during the steam-making process by the deposition of basic radicles as hydrates are the most important cause of corrosive action. Iron, aluminum, and magnesium are precipitated as hydrates that are later partly or completely converted into oxides. According to the chemical composition of the water the acid radicles that were in equilib-

[a] Boardman, A. J., Proper treatment of boiler feed water: Power and Engineer, vol. 30, 1909, p. 552.

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rium with these bases may do one or all of three things: They may pass into equilibrium with other bases, displacing equivalent proportions of carbonates and bicarbonates; or they may decompose carbonates that have been precipitated as scale; or they may combine with the iron of the boiler, thus causing corrosion. If these acids exceed the amount required to decompose the carbonate and bicarbonate radicles present the iron of the boiler is attacked, and the results are pits or tuberculations of the interior surface, leaks, particularly around rivets, and consequent deterioration of the boiler.

FOAMING.

Foaming is the formation of masses of bubbles on the surface of the water in the boiler and in the steam space above the water, and it is intimately connected with priming, which is the passage of water mixed with steam from the boiler. Foaming results when anything prevents the free escape of steam from the water. It may be due to particles of suspended matter, but usually the principal cause is an excess of dissolved substances that increases the surface tension of the liquid, and thereby reduces the readiness with which the steam bubbles break. Therefore the tendency of a water to foam varies inversely with the concentration it will undergo before developing an excessive surface tension. As the sodium and potassium salts remain dissolved in the boiler water while the greater portion of the other substances is precipitated, the foaming tendency is commonly measured by the degree of concentration of the alkaline salts in solution, because this figure considered in connection with the type of boiler determines the length of time that a boiler may run without danger of foaming.

REMEDIES FOR BOILER TROUBLES.

The best remedy for troubles caused by substances in feed waters is treatment of supplies before they enter boilers; this subject is considered under "Purification of water" (p. 251). When such treatment can not be given there are various ways of reducing potential injury. Low-pressure, large-flue boilers are frequently used in stationary plants in the Central States with hard waters, and it is said that the scale formed in them is softer and more flocculent and can therefore be more readily removed than that in high-pressure boilers. Blowing off is about the only practical means of preventing foaming, because this trouble is due principally to concentration of soluble salts in the residual water of the boilers. Accumulated sludge, or soft scale, can be removed by blowing, particularly in locomotive practice. In condensing systems much of the trouble due to mineral matter in the feed water is obviated because the quantity of raw water supplied is proportionately small. The problem is not

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completely solved in such systems, because the incrusting or corrosive action is transferred from the boiler to the condenser, which requires more or less cleaning and repairing in proportion to the undesirable qualities of the water supply.

BOILER COMPOUNDS.

Boiler compounds are widely used in regions where hard waters abound, but treatment within the boiler should be given only when it is impossible to purify the supply before it enters the boiler. If previous purification is not practicable the feed water frequently can be improved by judicious addition of chemicals. Many substances, ranging from flour, oatmeal, and sliced potatoes to barium and chromium salts, have been recommended for such use, but only two or three have proved to be truly economical. Cary[a] has classified these substances according to their action within the boiler. Those that attack chemically the scaling and corroding constituents precipitate the incrusting matter and neutralize acids. Soda ash, the commercial form of sodium carbonate, containing about 95 per cent Na_2CO_3, is the most valuable substance of this character, because it is comparatively cheap and its use is attended with the least objectionable results. Tannin and tannin compounds are also frequently used for the same purpose. Palmer[b] mentions the use of limewater to prevent corrosion and to obviate foaming, and it is probable that lime used with waters high in organic matter and very low in incrustants would improve them. The chemical reactions occurring when soda ash is used to remove the mineral constituents of water have been discussed at length in previous publications,[c] and it is not necessary to enter into details here. The proper amount to be used is a question to be decided for each water from its chemical composition and the style of boiler. The use of soda ash results in neutralizing of acids, precipitating the incrusting ingredients in a softer, more flocculent form, which is more easily removed from the boiler, and increasing the foaming tendency of the water by increasing its content of dissolved matter. Cary's second class of boiler compounds comprises those that act mechanically on the precipitated crystals of scale-making matter soon

[a] Cary, A. A., The use of boiler compounds: Am. Machinist, vol. 22, pt. 2, 1899, p. 1153.

[b] Palmer, Chase, Quality of the underground waters in the Blue Grass region of Kentucky: In Water-Supply Paper U. S. Geol. Survey No. 233, 1909, p. 187.

[c] Stabler, Herman, The mineral analysis of water for industrial purposes and its interpretation by the engineer: Eng. News, vol. 60, 1908, p. 355.

Cary, A. A., The use of boiler compounds: Am. Machinist, vol. 22, pt. 2, 1899, p. 1153.

Handy, J. O., Water-softening: Eng. News, May 26, 1904, p. 499.

Davidson, G. M., The C. & N. W. method of water treatment: Proc. Western Ry. Club, vol. 15, No. 6, Feb. 17, 1903.

Booth, W. H., Water softening and treatment, London, 1906.

Collett, Harold, Water softening and purification, London, 1896.

Christie, W. W., Boiler waters, New York, 1906.

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after they are formed, surrounding them and robbing them of their cement-like action. Glutinous, starchy, and oily substances belong to this class, but they are not now used to any considerable extent because they frequently thicken and foul the water more than they prevent the formation of hard scale. The third class comprises those that act mechanically, like those of the second class, and also partly dissolve deposited scale, thus loosening it and aiding in its ready removal. Kerosene is the most effective of such materials.

Many boiler compounds possessing or supposed to possess one or more of the functions just described are on the market, and the sale of them is very great. Some are effective and some are positively injurious. Most of them depend for their chief action on soda ash, petroleum, or a vegetable extract, but all are costly compared with lime and soda ash. Every engineer should bear in mind that a steam boiler is an expensive piece of apparatus and that fuel and boiler repairs are also expensive. Therefore he should hesitate to add substances to his feed water without competent advice regarding their effect. It is far more economical to have the water supply analyzed and to treat it effectively by certain well-known chemicals in proper proportion, either within or without the boiler, than to experiment with compounds of unknown composition.

NUMERICAL STANDARDS.

Stabler[a] in his excellent mathematical discussion of the quality of waters with reference to industrial uses gives several formulas by which waters may be classified. His methods of calculating the amount and the character of scale likely to result from use of a water are given as follows:

$$A = .00833Sm + .00833Cm + .0107Fe + .0157Al + .0138Mg + .0246Ca.$$

$$B = Sm + Cm + 1.3Fe + 1.9Al + 1.66Mg + 2.95Ca.$$

A represents pounds of scale per 1,000 gallons of water and B (computed from the preceding formula) represents parts per million of scale. Sm, Cm, Fe, Al, Mg, and Ca represent, respectively, the amounts in parts per million of suspended matter, colloidal matter (silica plus oxides of iron and alumium), iron, aluminum, magnesium, and calcium in the water. In this formula Ca should not exceed $.668CO_3 + .328HCO_3 + .417SO_4$, in which CO_3, HCO_3, and SO_4 represent, respectively, the amounts in parts per million of the carbonate, bicarbonate, and sulphate radicles present in the water. It is sometimes uncertain whether iron and aluminum are in solution or in colloidal state, but in applying these formulas to Indiana ground waters little error is introduced by assuming that Cm equals silica only. If it is desired to compute the scale-forming ingredients of waters whose analyses in this report give no values for silica, iron,

[a] Eng. News, vol. 60, 1908, p. 355.

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or aluminum, Cm may be taken as 20 and Fe and Al as zero, without introducing great error. In clear waters Sm would of course be zero; consequently for most Indiana ground waters the amount of scale may be estimated practically from the figures representing silica, calcium, and magnesium.

In the following Stabler formula C represents the amount of hard scale in pounds per 1,000 gallons of water and D the same in parts per million recomputed from the C formula; SiO_2, Mg, Cl, SO_4, Na, and K represent the respective amounts in parts per million of silica, magnesium, chlorides, sulphates, sodium, and potassium. If the alkalies are not separated, the figure representing sodium and potassium together and computed as sodium may be used with the Na coefficient in place of the last two terms of these formulas.

$C = .00833\ SiO_2 + .0138\ Mg + (.016Cl + .0118\ SO_4 - .0246Na - .0145\ K)$.

$D = SiO_2 + 1.66\ Mg + (1.92Cl + 1.42SO_4 - 2.95Na - 1.74\ K)$.

The ratio (b) between the amount of hard scale and the total amount of scale is an index of the probable hardness of the scale, expressed thus:

$$b = \frac{C}{A} = \frac{D}{B}$$

If b is not more than 0.25 the scale may be classified as soft; if between 0.25 and 0.5, as medium; and if more than 0.5, as hard. For other formulas and comments on those quoted the original article should be consulted.

The committee on water service of the American Railway Engineers and Maintenance of Way Association have offered [a] a classification of waters in their raw state that may be employed for approximate purposes, but, as the report states, "it is difficult to define by analysis sharply the line between good and bad water for steam-making purposes." The following table gives this classification with the amounts transformed to parts per million. In many Indiana waters the total incrusting and corrosive constituents are equivalent approximately to total solids.

Approximate classification of waters for boiler use according to proportion of incrusting and corroding constituents.

Parts per million.		Classification.
More than—	Not more than—	
.....	90	Good.
90	200	Fair.
200	430	Poor.
430	680	Bad.
680	.....	Very bad.

[a] Proc. Am. Ry. Eng. and Maintenance of Way Assoc., vol. 5, 1904, p. 595.

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These limits must be interpreted liberally in practice, because they are modified by the comparative hardness of the incrustation and the different extent of corrosion effected by waters of the same mineral content but of different chemical composition. Waters of the worst class may be improved by treatment in softening plants. The question how bad a water may be used without treatment can be decided by comparing the cost of artificially softening the water with the saving effected by the use of softened water. A report [a] of the committee on water service, just quoted, describes the principles on which such calculations should be based. In general, it is economical in locomotive service to treat waters containing 250 to 850 parts per million of incrustants and those containing less than the lower amount if the scale formed contains much sulphates.[b] As the incrusting solids may commonly be reduced to 80 or 90 parts per million, the economy of treating boiler waters deserves consideration in a region where most of the supplies contain 300 to 500 parts per million of incrusting and corrosive matter. The amount of mineral matter that makes a water unfit for boiler use depends on the combined effect in boilers of the softening reagents used with such waters and of the constituents not removed by softening. Substances added to a supply to remove incrustants or to prevent corrosion increase the foaming tendency, and this increase may be great enough to render a water useless for steaming purposes. It is not of much benefit to soften a water containing more than 850 parts per million of nonincrusting material and much incrusting sulphates.[b] Waters containing over 400 parts per million of alkali salts may be classed as bad for boiler use.[c] Though waters containing as high as 1,700 parts per million of foaming constituents have been used, it is usually more economical to incur considerable expense in replacing such supplies by better ones.

WATER FOR OTHER INDUSTRIAL USES.

GENERAL STATEMENT.

The manufacture of many articles is affected by the ingredients of natural waters. The quality of water for boiler service has already been discussed; with reference to factories it need only be added that increase of boiler efficiency often justifies purification of bad water when increased value of the manufactured product alone may not be considered to do so. This observation applies particularly to paper, pulp, and strawboard mills, laundries, and other establishments where large quantities of water are evaporated to furnish steam for drying, and to ice factories and similar plants where distilled water is

[a] Proc. Am. Ry. Eng. and Maintenance of Way Assoc., vol. 8, 1907, p. 601.
[b] Idem, vol. 6, 1905, p. 610.
[c] Idem, vol. 9, 1908, p. 134.

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produced. But besides its use for steam making water plays a specific part in many manufacturing processes. In paper mills, strawboard mills, bleacheries, dye works, canning factories, pickle factories, creameries, slaughterhouses, packing houses, nitroglycerin factories, distilleries, breweries, woolen mills, starch works, sugar works, canneries, glue factories, soap factories, and chemical works water becomes a part of the product or is essential in its manufacture. As the principal function of water in most of these establishments is that of a cleansing agent or a vehicle for other substances, a supply free from color, odor, suspended matter, microscopic organisms, and especially bacteria of fecal origin, and fairly low in dissolved substances, especially iron, generally is satisfactory; but there are some exceptions. Water hygienically acceptable is necessary where it comes in contact with or forms part of food materials, as in the making of beverages, starch, and dairy or meat products. As all these ideal conditions are infrequently encountered in natural supplies, the manufacturer is confronted with the problems of ascertaining what degree of freedom from these substances is necessary to prevent injury to his machinery or to his output and whether the cost of obtaining such purity is counterbalanced by decreased cost of production and increased value of product. Competitive business methods and increased facilities of transportation have standardized the values of manufactured articles so thoroughly that makers are now obliged to scrutinize carefully every item of production cost in order to obtain reasonable profits. Therefore any appreciable saving effected by improvement of the water supply is one of the easiest sources of profit for the manufacturer.

The effects in some industries of the substances most commonly found in water are here outlined. The treatment is not exhaustive, the object being to offer approximate standards to aid in classification.

EFFECT OF FREE ACIDS.

Free mineral acids, such as sulphuric acid in drainage from coal mines or hydrochloric acid in the effluents of some industrial establishments, are especially injurious and nearly always necessitate purification. In paper mills, cotton mills, bleacheries, and dye works acids decompose chemicals and streak the fabrics, besides rotting them. They also corrode metal work, rapidly destroying screens, strainers, and pipes. Such effects are likely to follow the use of water that contains a measurable amount of free mineral acid.

EFFECT OF SUSPENDED MATTER.

Suspended matter in surface waters may be of vegetable, mineral, or animal origin, as it consists of particles of sewage, bits of leaves, sawdust, sticks, or sand and clay. The silt so common in rivers of the

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West is largely derived from sand and clay. Few well waters contain suspended animal or vegetable matter, but many carry finely divided sand and clay, and they frequently become turbid by precipitation of dissolved ingredients. Suspended matter is objectionable in all processes in which water is used for washing or comes into contact with food materials, because it is likely to stain or spot the product. For this reason even a small amount of suspended matter due to precipitated iron is especially injurious. Small amounts (10 to 20 parts per million) of suspended vegetable or animal matter liable to decomposition or to partial solution are much more objectionable than equal quantities of mineral matter. For these reasons water should be freed from suspended matter before being used for laundering, bleaching, wool scouring, paper making, dyeing, starch and sugar making, brewing, distilling, and similar processes. In making the coarser grades of paper, such as strawboard, a small amount of suspended matter is not especially injurious, but for the finer white and colored varieties clear water is essential.

EFFECT OF COLOR.

Color in water is due principally to solution of vegetable matter, and materials bleached, washed, or dyed with light shades in colored water are likely to become tinged. Highly colored waters can be used in making wrapping or dark-tinted papers, but not the white grades, and paper manufacturers are put to great expense for water purification on that account. The lower waters are in color, therefore, the more desirable they are for use in bleacheries, dye works, paper mills, and other factories where fabrics are likely to acquire undesirable brown tints.

EFFECT OF IRON.

Iron is the most undesirable dissolved constituent and its presence in comparatively small quantities necessitates purification. Many ground waters contain 1 to 20 parts per million of iron, which may be precipitated by exposure to the air and by release of hydrostatic pressure, causing the waters to become turbid; such waters often develop growths of *Crenothrix* (see p. 235) that interfere in many industrial operations. In all cleansing processes, especially if soap or alkali is used, precipitated iron is likely to cause rusty or dull spots. In contact with materials containing tannin compounds iron forms greenish or black substances that discolor the product. Therefore many waters containing amounts even as small as 1 or 2 parts per million of iron have to be purified before they can be used industrially. In water for dye works iron is especially objectionable and it commonly prevents the use of the water without purification.[a]

[a] Sadtler, S. P., A handbook of industrial organic chemistry, Philadelphia, 1900, p. 483.

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Iron in the water supply of paper mills may be precipitated on the pulp, giving it a brown color, or during sizing or tinting, giving spotty effects. Water containing much iron can not be used in bleaching fabrics, because salts that spot the goods are formed. The dark-colored compounds that iron forms with tannin discolor hides in tanning and barley in malting, and also give beer bad color, odor, and taste.[a]

EFFECT OF CALCIUM AND MAGNESIUM.

Calcium and magnesium are similar in their industrial effects and they usually vary together in amount, waters carrying 10 to 50 per cent as much magnesium as calcium. In most Indiana waters calcium and magnesium are the predominating bases. In boiling processes some calcium and magnesium are precipitated on whatever is boiled in the water, and this deposit may interfere with later operations because it covers the material. As these two basic substances decompose equivalent amounts of many chemicals employed in technical operations they are a cause of waste, and the alkaline-earth compounds thus formed on fabrics also interfere with later treatment. This is the chief trouble with calcareous waters and the greatest argument in favor of preliminary softening. Some of the chemicals used to disintegrate the fibers in making pulp are consumed by the calcium and magnesium in the water supply, but the loss from this source is not nearly so great as that occurring later when the resin soap used in sizing the paper is decomposed by the calcium and magnesium. The insoluble soaps thus created do not fix themselves on the fibers, but form clots and streaks. Similar decomposition of valuable cleansing materials and subsequent deposition of insoluble compounds take place in laundering, wool scouring, and similar processes. In the manufacture of soap calcium and magnesium form with the fatty acids curdy precipitates that are insoluble in water and therefore have no cleansing value. Many dyeing operations are interfered with by calcium and magnesium, which neutralize chemicals and change the reaction of the baths, besides forming insoluble compounds with many dyes. Highly calcareous waters can not be used for boiling the grain in distilleries because proper action is hindered by deposition of alkaline-earth salts on the particles of grain, nor for diluting spirits because they cause turbidity.[b] Very soft water, on the other hand, is said to be undesirable in paper mills for loading papers with any form of calcium sulphate because such waters dissolve part of the loading materials.[c] Probably waters high in chlorides would also be bad for this purpose because chlorides increase the solubility of calcium sulphate.

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[a] De la Coux, M. A. J., L'eau dans l'industrie, Paris, 1900, pp. 187 and 232.

[b] Idem, p. 251.

[c] Cross, C. F., and Bevan, E. J., A text-book of paper making, New York, 1900, p. 294.

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EFFECT OF CARBONATES.

The effects of carbonates and bicarbonates in waters used in industrial processes are not differentiated in this paragraph. It is not uncommon to estimate the combined carbonic acid and to state it as the carbonate (CO_3) without distinguishing between the carbonate (CO_3) and bicarbonate (HCO_3), though in many natural waters the carbonate radicle is absent, the combined carbonic acid being present in the form of bicarbonates. If hard waters proportionately high in carbonates and low in sulphates are boiled the bicarbonate radicle is decomposed, free carbonic acid is given off, and the greater part of the calcium and magnesium is precipitated. For this reason waters of that character are generally more desirable for industrial operations than waters high in sulphates and low in carbonates, as boiling does not greatly reduce the amount of the hardening constituents under the latter conditions. In beer making waters high in carbonates are said to produce dark-colored beers with a pronounced malt flavor because the carbonates increase the solubility of the nitrogenous bodies, whereas waters high in sulphates yield pale beers with a definite hop flavor because the sulphates reduce the solubility of the malt and the coloring matters.[a]

EFFECT OF SULPHATES.

The influence of sulphates in beer making has been noted. Hard waters with sulphates predominating are desirable in tanning heavy hides because they swell the skins, exposing more surface for the action of the tan liquors.[b] Sulphates interfere with crystallization in sugar making so that the amount of sugar retained in the mother liquor is increased.

EFFECT OF CHLORIDES.

High chlorides in most Indiana waters are accompanied by high alkalies. Appreciable amounts of chlorides are injurious in many industrial processes. Beverages and food products, of course, can not be treated with waters very high in chlorides without becoming salty. In tanning, chlorides cause the hides to become thin and flabby.[b] Animal charcoal used in clarifying sugar is robbed of its bleaching power by absorption of salt, and chloride-bearing waters also affect the quality of sugars because saline salts are incorporated in the crystals.[c] In the preparation of alcoholic beverages chlorides in large amount prevent the growth of the yeast and interfere with the germination of the grain. The only way of removing chlorides from water that has been commercially developed is by distillation. The

[a] Brewing water, its defects and remedies, New York, 1909, p. 19. Also De la Coux, op cit., p. 169.

[b] Parker, H. N., Stream pollution [in Potomac River basin]: Water-Supply Paper U. S. Geol. Survey No. 192, 1907, p. 194.

[c] De la Coux, op. cit., p. 152.

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cost of this process has been greatly reduced by use of multiple-effect evaporators, and this method of purification is worth consideration where chloride-bearing waters must be used.

EFFECT OF ORGANIC MATTER.

Organic matter of fecal origin is of course dangerous in any water supply that comes into contact with food products, and water so polluted should be purified before being used. Care in this respect is particularly necessary in creameries, slaughterhouses, canneries, pickle factories, distilleries, breweries, sugar factories, and starch works. Organic matter not necessarily capable of producing disease is undesirable in industrial supplies because it induces decomposition in other organic materials—like cloth, yarn, sugar, starch, meat, or paper—rotting and discoloring them.

EFFECT OF HYDROGEN SULPHIDE.

Hydrogen sulphide (H_2S) is a gas with an odor like that of rotten eggs, and it occurs dissolved in some underground waters. It is corrosive even in small quantities, and it also injures materials by discoloring and rotting them. This substance is associated with so much dissolved salts in many waters that they are unfit for industrial use for reasons other than their gaseous content.

EFFECT OF OTHER SUBSTANCES.

Silica and aluminum are usually not present in sufficient quantity to have any appreciable effect in industrial processes, except when water is evaporated. Large quantities of sodium and potassium, by adding to the amount of dissolved matter, are objectionable in some manufacturing operations. Phosphates, nitrates, and some other substances not noted in this outline interfere with industrial chemical reactions, but they are seldom present in natural waters in sufficient quantity to have noticeable effect.

WATER FOR MEDICINAL USE.

The relation between the constituents of natural waters and their physiologic action has been discussed at length in the works of Cohen,[a] Crook,[b] and others. An excellent article by Hessler[c] refers especially to the mineral waters of Indiana. Blatchley[d] has

[a] Cohen, S. S., System of physiologic therapeutics, vol. 9, Philadelphia, 1902.

[b] Crook, J. K., The mineral waters of the United States and their therapeutic uses, New York, 1899.

[c] Hessler, Robert, The medicinal properties and uses of Indiana waters: Twenty-sixth Ann. Rept., Indiana Dept. Geology and Nat. Res., 1903, p. 159; also The mineral waters of Indiana, with indications for their therapeutic application: Trans. Indiana State Med. Soc., 1902.

[d] Blatchley, W. S., The mineral waters of Indiana: Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1903, p. 11.

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described 16 mineral waters in the 19 counties included in this report. To note a few features that are often forgotten or disregarded in considering the application of mineral waters may not be out of place.

The term "mineral" may reasonably be applied to all natural waters, as all contain dissolved mineral matter, but in general practice it is restricted to those that are exploited on account of their supposedly specific physiologic action. The term "medicinal" is sometimes used to distinguish highly mineralized waters from those that are low in mineral constituents and are especially acceptable as table waters by reason of their physical characteristics. The most logical classification of waters for discussing their chemical constituents in relation to therapeutics is that of Peale[a] as modified by Haywood[b] for the ionic form of stating analyses of water, though Haywood's system is somewhat misleading in a few minor details. It is a strictly chemical classification, by which waters are grouped according to their reaction and their predominating basic and acid radicles, so that the name conveys a statement of the principal active substances.

The therapeutic application of water, or its use for the correction of diseased conditions of the human body, has always been recognized in scientific writings, and the continued and increasing patronage of mineral-spring resorts and the undoubted improvement of many patients treated there clearly indicate that natural waters have curative properties. Yet the frequent claims of miraculous recovery by the use of mineral waters, together with the extravagant statements regarding the waters, can but rouse skepticism as investigation reveals how meagerly such claims are supported by evidence. Statement of analyses in hypothetical combination adds to the confusion, because the identity and the number of the compounds calculated depend on the judgment of the analyst and not on his laboratory data. Therefore comparison of the analyses of different waters is rendered difficult and misleading. Lithium, for instance, is said to be a particularly valuable ingredient; yet many analysts report lithium carbonate, sulphate, or chloride in waters in spite of the fact that the physiologic action is due mainly to the lithium itself and not to lithium carbonate in distinction from the chloride or the sulphate or, in other words, that the action takes place only when the salt is dissociated. If different lithium compounds are reported, it is impossible to measure the effect of the lithium, unless it is recognized that 5.3 parts per million of lithium carbonate, 6.1 parts of lithium chloride, 7.9 of the sulphate, and 9.7 of the bicarbonate contain

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[a] Peale, A. C., The natural mineral waters of the United States: Fourteenth Ann. Rept. U. S. Geol. Survey, 1894, pt. 2, p. 53; also, The classification of American mineral waters: Trans. Am. Climatological Assoc., May 31, 1907; also, introductory chapter on the classification of mineral waters in Cohen's System of physiologic therapeutics, vol. 9, 1902, p. 299.

[b] Haywood, J. K., and Smith, B. H., Mineral waters of the United States: U. S. Dept. Agr., Bur. Chemistry, Bull. 91, 1905, p. 9.

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each exactly 1 part of lithium. The curative properties of some waters are attributed to minor ingredients that are present in comparatively insignificant quantities, and many waters containing much less than 1 part per million of lithium are widely advertised as lithia waters. Though it is true that many drugs are as efficient when given in very small but frequent doses as when given in one large dose, the therapeutic value of 1 part per million of lithium may well be questioned, because a physician would have to prescribe 200 tumblerfuls of the water in order to administer an ordinary minimum dose of lithium. The physiologic effect of these minor ingredients is usually overshadowed by that of other substances present in much larger quantities. Many strong brines, for example, contain considerable amounts of lithium, but, as Hessler states,[a] the effect of 10 parts of lithium in the presence of 1,000 or more parts of chlorides would probably be insignificant as compared with the effect of the saline constituents. Many mineral springs are found to possess radioactivity, and this characteristic has been advanced as explaining their curative qualities. So far as the writer is informed, however, no acceptable proof of this theory has been advanced. On the other hand, the beneficial effect on the human body of water itself, both hot and cold, used internally or externally, is thoroughly recognized in therapeutics, and the curative qualities of waters not containing appreciable amounts of physiologically active substances may be attributed as reasonably to the action of water itself, combined with a normal regimen of diet, exercise, and other hygienic restrictions, as to some mysterious quality or substance yet undiscovered.

PURIFICATION OF WATER.

GENERAL DISCUSSION.

Purification of water is removal or reduction in amount of substances that render waters in their raw state unsuitable for use. It is practiced on a large scale with one or more of three objects in view: First, to render a supply safe and unobjectionable for drinking; second, to reduce the amount of the mineral ingredients injurious to boilers; third, to remove substances injurious to the machinery or to the manufactured product in industrial processes. The largest purification plants in this country have been constructed in order to produce potable waters without special attention to other possible uses, and some waters need no further treatment before being suitable for steaming and for general industrial purposes. But many other waters are hard, and increased appreciation of the value of good water has resulted in demand for the removal of the hardening con-

[a] Hessler, Robert, The mineral waters of Indiana, with indications for their therapeutic application: Trans. Indiana State Med. Soc., 1902.

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stituents also. An excellent example of the result of such insistence is the recently installed plant at New Orleans, where hard, colored, turbid, sewage-polluted river water is brought up to practically all industrial and domestic standards of purity.

Removal of bacteria, especially those causing disease, and removal of turbidity, odor, taste, and iron are the principal requirements in purification of a municipal supply, elimination of bacteria and suspended matter being the most important. The most common methods of effecting such purification are slow filtration through sand and rapid filtration after coagulation, both methods usually being combined with sedimentation. The first process is known as slow sand filtration and the second as mechanical filtration. The efficiency of such filters is measured primarily by the ratio between the number of bacteria in the applied water and the number in the effluent. This figure, stated in percentage of removal, should be as high as 98 and often reaches 99.8 per cent with a filter of either kind operated carefully under normal conditions.

Removal of scale-forming and neutralization of corrosive constituents are the chief aims in preparing water for steam making. Two general methods are employed, namely, cold chemical precipitation followed by sedimentation, and application of heat with or without chemicals, usually followed by rapid filtration. The first process is carried on in cold-water softening plants and the second in feed-water heaters.

The requirements of the water supplies for industries are so varied that classification of purification methods is difficult. Water properly prepared for domestic and for boiler use is suitable for most industrial establishments, and it is more economical for small manufacturers in large cities to buy such water from water companies than to maintain private supplies and purification apparatus. It is usually cheaper, however, for large factories to be supplied from separate sources, not only because of saving in actual cost of water but also because of the opportunity thus afforded of procuring water specially adapted to the needs of the factory. The common methods of industrial water purification are those already mentioned, or combinations of them, modified to meet particular needs. In a few industrial processes, notably the manufacture of ice by the can system, water practically free from all dissolved and suspended substances is necessary, and distilled water must be manufactured. Distillation is expensive, though the employment of multiple-effect evaporators has greatly reduced the cost of operation.

Besides the four common systems of purification many minor processes are used, sometimes alone but more frequently as adjuncts to filters or softeners. Surface waters are screened through wooden or iron grids or through revolving wire screens to remove sticks and

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leaves before other treatment. Coarse suspended matter can be removed by rapid filtration through ground quartz or similar material in units of convenient size provided with arrangements for washing the filtering medium, similar to those used in mechanical filters. Very turbid river waters are first allowed to stand in large sedimentation basins to reduce the cost of operating the filters. Supplies objectionable only because of their iron content are aerated by being sprayed into the air or by being allowed to trickle over rocks, or by other methods causing evaporation of carbonic acid and absorption of oxygen. Such a process precipitates and oxidizes the iron in solution so that it can readily be removed by rapid filtration. Similar aeration is often employed to evaporate and oxidize dissolved gases that cause objectionable tastes and odors.

Disinfection by ozone, copper sulphate, calcium hypochlorite, and many other substances kills organisms that may cause disease or impart bad odors and tastes. Purification of this character must be done with substances that will destroy the objectionable organisms without making the water poisonous to animals. Such treatment is especially adapted for sewage[a] but it is also employed in connection with filtration of municipal supplies. Natural purification of water is accomplished largely through the biological processes mentioned by Hazen,[b] in which the organic matter is oxidized by serving as food for bacteria and objectionable organisms are destroyed by the production of conditions unfavorable to their existence. Action of this kind takes place in reservoirs and lakes, and it is also relied upon in many processes for the artificial purification of sewage.[c]

SLOW SAND FILTRATION.

Slow sand filtration consists in causing the water to pass slowly downward through a layer of sand of such thickness and fineness that the requisite removal of suspended substances is accomplished. The filter is also called the continuous and the English filter. On the bottom of a water-tight basin commonly constructed of concrete perforated tiles or pipes laid in the form of a grid are covered with a foot of gravel graded in size from 25 to 3 millimeters in diameter from bottom to top, and a layer of fine sand 3 to 4 feet in depth is put over the gravel, which serves only to support the sand. When water is applied on the surface it passes through the sand and the gravel and flows away through the underdrain. The suspended materials, including bacteria, are removed by the sand, the action of which is rendered more efficient by the rapid formation of a mat of finely

[a] Phelps, E. B., The disinfection of sewage and sewage filter effluents; Water-Supply Paper U. S. Geol. Survey No. 229, 1909.

[b] Hazen, Allen, Clean water and how to get it, New York, 1907, p. 83.

[c] Winslow, C.-E. A., and Phelps, E. B., Investigations on the purification of Boston sewage, with a history of the sewage-disposal problem: Water-Supply Paper U. S. Geol. Survey No. 185, 1906.

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divided sediment on the surface. When this film has become so thick that filtration is unduly retarded, the water is allowed to subside below the surface and about half an inch of sand is removed, after which filtration is resumed. The sand thus taken off is washed to free it from the collected impurities, and it is replaced on the beds after they have been reduced by successive scrapings to a thickness of about 20 inches. As cleaning necessitates temporary withdrawal of filters from service, they are divided into units of convenient size, usually half an acre each, so that the operation of the system may not be interrupted. Filters may be roofed and sodded; this facilitates cleaning by preventing the formation of ice, permits work on the filter beds in all kinds of weather, and inhibits algæ growths.

The foregoing are the essential features of a slow sand filter, but several adjuncts render this system more efficient. A clear-water basin for the filtered supply, covered to prevent deterioration of the water, is provided in order that the varying rate of consumption may not affect the rate of filtration. Clarification of turbid water is rendered more economical by allowing it to stand for one to three days, during which a large portion of the suspended matter is deposited, so that the time between sand scrapings is lengthened. Another form of pretreatment is passage through roughing, or preliminary, filters consisting of beds of slag, sponge, or stone, the water flowing at 15 to 20 times the rate in sand filters. A very large proportion of the suspended matter is thus removed. Objectionable odors and tastes may be obviated by aeration before or after filtration. Killing the bacteria before filtration by use of ozone or other germicides has also been proposed.

Slow sand filtration removes practically all the suspended matter and the bacteria. Color is only slightly reduced, and the hardness is not changed. The process is especially adapted to waters low in color, suspended matter, and animal pollution. Very small particles of clay are not removed by these filters and for waters containing them only for limited periods the addition of a coagulant before filtration has been proposed.[a] It can readily be seen that the efficiency of this kind of filter depends largely on the character of the sand, as the ability to prevent the passage of suspended matter is governed by the size of the spaces between the sand particles. The rate of filtration depends on the average size of the sand particles, the thickness of the sand bed, the head of water, and the turbidity. Under ordinary conditions of operation in the United States the rate in slow sand filters preceded by sedimentation is 2,000,000 to 4,000,000 gallons per acre per day.

[a] Report of Hering, Fuller, and Hazen on the methods of purifying the water supply of the District of Columbia: Senate Rept. 2380, 56th Cong., 2d sess.

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MECHANICAL FILTRATION.

The distinctive features of the mechanical process are the use of a coagulant and the high rate of filtration. The term "mechanical" is applied because of the contrivances for washing the filtering medium; the filter is also known as the American filter. The raw water during its entrance into the sedimentation basin, which is smaller than that used with slow sand filters, is treated with a definite proportion of some coagulant, which forms by its decomposition a gelatinous precipitate that unites and incloses the suspended material, including the bacteria, and absorbs the organic coloring matter. This combined action destroys color and makes suspended particles larger and therefore more readily removable. When aluminum sulphate, the coagulant most commonly used, is decomposed aluminum hydrate is precipitated and the sulphate radicle remains in solution, replacing an equivalent amount of carbonate, bicarbonate, or hydroxyl radicles. The natural alkalinity of many waters is sufficient to effect this reaction. According to Hazen [a] 1 part per million of ordinary aluminum sulphate should be allowed 0.6 part of alkalinity expressed as $CaCO_3$ to insure complete decomposition. If the alkalinity is not high enough, part of the aluminum sulphate remains in solution and good coagulation does not take place. Therefore lime or soda ash is added if the alkalinity is too low. The proper amount of aluminum sulphate to be used is determined by the amounts of color, organic matter, and suspended matter, and by the fineness of the suspended matter, and it is best ascertained by direct experimentation with the water to be purified. Ferrous sulphate is sometimes used instead of aluminum sulphate; lime must always be added with it in order to bring about proper coagulation.

The water with the coagulant is allowed to stand three or four hours in the sedimentation basin, where a large proportion of suspended particles is deposited. It is then passed rapidly through beds of sand or ground stone to remove the rest of the suspended matter. Many filters now in use are built of wood or iron in cylindrical form 10 to 20 feet in diameter, and some are designed so that filtration can be hastened by pressure. The sand, 30 to 50 inches deep, rests on a metallic floor containing perforations large enough to allow ready issue of the water but small enough to prevent passage of sand grains. When the filter has become clogged the flow of water is reversed, filtered water being forced upward through the sand to wash it and to remove the impurities, which pass over the top of the filter with the wasted water. A revolving rake with long prongs projecting downward into the sand mixes it during washing and prevents it from becoming graded into spots of coarse or fine particles. In recently constructed

[a] Hazen, Allen, Report of filtration commission of the city of Pittsburg, 1899, p. 57.

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works rectangular filters 300 to 1,300 square feet in area have been built, and compressed air forced through the sand at intervals is used instead of a revolving rake for agitating the sand during washing. Larger orifices in the strainers are also being used and the introduction of sand is prevented by fine gravel over the strainer pipes. The rate of filtration is from 80,000,000, to 180,000,000 gallons per acre per day. The time between washings is six to twelve hours, depending principally on the turbidity of the water applied to the filter, and 4 to 8 per cent of the water filtered is consumed in washing.

Mechanical filtration removes practically all suspended matter, reduces the color to an amount that is unobjectionable, and part of the dissolved iron is removed under some conditions. The permanent hardness of the water is increased in proportion to the amount of sulphate radicle added as aluminum sulphate, and if only enough lime to decompose the coagulant is added, the total hardness is increased. If larger amounts of lime are added, however, the hardness is reduced. If soda ash is used in place of lime the foaming constituents of the water are increased. The chemicals are always added in solution. As this method of filtration is used almost entirely for river waters, with fluctuating contents of suspended and dissolved matter, proper operation requires constant and intelligent attention.

COLD-WATER SOFTENING.

The principal object of water softening is to remove the substances that cause incrustations in boilers, particularly calcium and magnesium, and to neutralize those that cause corrosion. Chemicals of known strength properly dissolved in water are added to the raw supply in such proportion as to precipitate all the dissolved constituents that can be economically removed by such treatment. The water is then allowed to stand long enough to permit the precipitate to settle, after which the clear effluent is drawn off; or, if more rapid operation is desired, filters of the rapid type may be used after sedimentation. The water softeners on the market differ only in the precipitant, in the filtering medium if one is used, and in the mechanism regulating the incorporation of the chemicals with the water.

Among the substances that have been proposed as precipitants are sodium carbonate, silicate, hydrate, fluoride, and phosphate, barium carbonate, oxide, and hydrate, and calcium oxide, but of these substances lime and soda ash are almost exclusively used on account of their excellent action and comparative cheapness. When soda ash (Na_2CO_3) and lime dissolved in water to form a solution of calcium hydrate [$Ca(OH)_2$] are added to a water in proper proportion, free acids are neutralized, free carbon dioxide is removed, the bicarbonate radicle is decomposed, and iron, aluminum, and magnesium hydrates

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and calcium carbonate are precipitated. These four basic substances are removed to the extent of the solubility of these compounds in water, and the calcium added as lime is also precipitated, but the sodium from the soda ash remains in solution in the softened water. The precipitate in settling takes down with it a large proportion of the suspended matter. The filters are thin beds of coke, sponge, excelsior, wool, or similar material, through which the water is passed at a very rapid rate to remove particles that have not subsided in the tanks.

Such treatment with lime and soda ash removes a large percentage of the iron, aluminum, calcium, magnesium, carbonates, bicarbonates, and free carbon dioxide and suspended matter, and part of the silica and the organic matter; in other words, the incrusting constituents are removed. Sodium, potassium, sulphates, and chlorides are left in solution, and the alkalies are increased in proportion to the quantity of soda ash that is added; that is, the foaming constituents are increased, and this fixes the maximum amount of incrustants that can be treated. The minimum amount of incrustants in a treated water is determined by the solubility of the precipitated substances and by the completeness of the reaction between the added chemicals and the dissolved matter. It is about 90 parts per million. The sulphate radicle can be removed by using barium compounds, which precipitate barium sulphate, but the poisonous effect of even small amounts of barium is a great objection to its use. The chlorides are not changed in amount by water softening. The chemicals should be very thoroughly mixed with the raw water and sufficient time should be allowed for complete reaction, which proceeds rather slowly, for otherwise precipitation will occur later in pipe lines or in boilers.

FEED-WATER HEATING.

Water heaters are designed primarily to utilize waste heat in stationary boiler plants by raising the temperature of the feed water and thereby lessening the work of the boilers themselves. This is their primary function, but some purification of water occurs in them and many heaters have been specially constructed to take advantage of that effect. The heat is derived from exhaust steam or from flue gases, and the heaters utilizing steam are either open—that is, operated at atmospheric pressure—or closed and operated at or near boiler pressure. In accordance with these three conditions, which result in distinct purifying effects, feed-water heaters are classified as open or closed or economizers, the last being those using flue gases. Open heaters are best adapted for removing large quantities of scale-forming material. In most forms the steam enters at the bottom

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and the water at the top, and intimate contact between the two is obtained by spraying the water or by allowing it to trickle over or to splash against plates. In this manner the water is quickly heated nearly to boiling temperature. Dissolved gases are expelled, the bicarbonate radicle is decomposed, and iron, aluminum, part of the magnesium, and calcium equivalent to the carbonates after decomposition of the bicarbonates are precipitated as hydrates, oxides, or carbonates under varying conditions of temperature, pressure, and time. The precipitate agglomerates the particles of suspended matter and makes them more readily removable by sedimentation and filtration. The slowness with which the reactions take place and the presence of acid radicles other than carbonates to hold the bases in solution prevent complete removal of calcium and magnesium. The addition of soda ash in proper proportion, however, effects fairly complete precipitation of the alkaline earths, and apparatus for constant introduction of this chemical in solution may be provided. After the precipitate has been formed the water passes through filters of burlap, excelsior, straw, hay, wool, coke, or similar material, arranged in units that can be readily cleaned. Open heaters operated without a chemical precipitant remove substances that are soft and bulky and leave in the water the constituents that form hard scale; therefore scale from water treated in such heaters is not so great in amount but is harder than that formed by the raw water.

In closed heaters the water is passed either through metal tubes surrounded by steam or around steam pipes, and manholes or other openings are provided for cleaning the scale from the tubes. As the water is heated under pressure some precipitation takes place, but closed heaters are not nearly so efficient in this respect as open heaters because there is no provision for the escape of the gases liberated from the water.

Economizers consist essentially of water tubes set in the flues leading from the furnaces. Facilities are provided for cleaning scale from the inside and soot from the outside of the tubes. As economizers are heated by flue gases, the water in the tubes under boiler pressure can be heated to a much higher temperature than in open or closed heaters, and boiler conditions as described on pages 238–244 are approximated. The precipitation of incrustants varies greatly with the normally fluctuating temperature of the flue gases.

CHEMICAL COMPOSITION OF THE WATERS.

WATER FROM THE UNCONSOLIDATED DEPOSITS.

In the tables in the body of the report 169 analyses are given of waters from wells drawing their supplies from the unconsolidated deposits of sand, clay, gravel, and alluvium overlying the solid rock.

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The sources of water range in depth from 10 to 230 feet. They can not be differentiated, except in respect to depth of the well and geographic position, not only because it was impossible to procure information regarding the depth and character of the water-bearing strata of each well, but chiefly because most of the deeper wells yield mixed waters from two or more beds. Indeed, sharp distinction between the different water-bearing sands and gravels, though interesting, would hardly be profitable, on account of the heterogeneous nature of the unconsolidated deposits and the extremely local value of such detailed study in comparison with its importance in revealing the chemical composition of the waters.

The quality of the waters from the unconsolidated deposits, as indicated by averaging all the analyses, is shown in line A of the following table. Many of the analyses are incomplete, because the alkalies were not determined; and the figure for sodium and potassium is therefore the one most likely to be in error in all the averages. In order to ascertain whether drift waters from different parts of the region are similar it was divided into four parts by east and west lines and the analyses for each part were averaged as a group. The figures in lines B, C, D, and E represent the average quality of the waters from the unconsolidated deposits in the north, north middle, south middle, and south tiers of counties respectively. Bicarbonates, sulphates, and total solids show definite increase from north to south; the other figures are either similar or inconclusive on account of the small number of quantities averaged. In total mineral content the average for wells in the north tier is 72 parts lower and in the south tier 108 parts higher than the average for all in line A; yet inspection of the individual analyses in each group proves that waters from wells in different parts of the same township may diverge from one another far more widely in essential characteristics than waters from different tiers of counties. Many waters in the northern part of the region carry more than 600 parts of total solids and many in the southern part less than 400 parts. Therefore it must be concluded that the quality of water from the unconsolidated deposits has no relation to geographic position in this region, except that possibly the waters in the southern part may be slightly more highly mineralized than those in the northern part.

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Quality of waters from the unconsolidated deposits.

[Parts per million except as otherwise stated.]

	Number of analyses.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
A....	169	18	0.8	91	31	18	0.0	306	76	2.8	47	467
B....	71	17	.7	83	29	13	.0	290	57	3.7	76	395
C.....	37	21	1.0	95	29	11	.0	292	76	2.0	18	464
D....	37	24	.8	98	33	9	.0	319	98	2.2	23	520
E....	24	17	.9	96	35	44	.0	359	100	2.5	45	575
F....	45	.....	.3	110	36	21	.0	310	136	3.3	50	619
G....	.....	4.1	a.3	20.9	7.1	4.1	34.6	.....	17.5	.6	10.8	.....

a Fe_2O_3.

A. Average of all analyses of water from unconsolidated deposits.
B, C, D, and E. Average of all analyses arranged in four groups from north to south geographically.
F. Average of analyses of water from wells less than 30 feet deep. Na+K calculated.
G. Percentage composition of anhydrous residue computed from A.

Consideration of quality in reference to depth reveals no striking relation except that many shallow wells are more highly mineralized than deeper ones. Forty-five of the 169 waters are from wells less than 30 feet deep, and the average of their analyses is given in line F of the foregoing table, the alkali figure being computed from the other estimates. All the constituents are higher than in line A, and calcium and sulphates are especially high. The difference is more marked in the southern than in the northern half of the territory, for the total solids of all waters from shallow wells reported from the two southern tiers of counties exceed 1,000 parts. The small number of analyses available for discussion, however, makes it uncertain whether this difference is general, and it is therefore unwise to indulge in speculation on this topic.

Though the individual waters in the drift differ from each other in their concentration and to a less extent in the relative amounts of mineral matter that they contain, they are all of the same general type. They contain from 250 to 1,000 parts per million of total solids and they range from fair to bad for boiler use. Some of them contain so much iron that they are undesirable for laundry use, and most of them carry calcium and magnesium enough to make it necessary to soften them with chemicals before using them for washing. Generally the waters are acceptable for drinking. The average total hardness expressed as $CaCO_3$ is 360 parts per million, and the average total incrustants are 340 parts per million, or 2.82 pounds per 1,000 gallons. The average chemical composition of the anhydrous residue, given in line G, indicates that the waters are of the alkaline class, with bicarbonates largely predominating and with sulphates, chlorides, and alkalies usually present only in nominal amounts. The ratio of calcium to magnesium averages 3 and ranges normally from 2 to 5.

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WATER FROM THE ROCK.

Two distinct types of water are contained in the formations underlying the drift in this area, and the relative position of the rocks that bear them can readily be understood from the generalized section on page 36. The lower limestones and sandstones yield hard, salt waters, generally carrying hydrogen sulphide; the upper limestones yield waters that are hard but not salty and are not impregnated with hydrogen sulphide except by intrusion from below. In the tables in the body of this report 88 analyses are given of waters coming wholly or mainly from the rock, and five of the analyses evidently represent the supply from the lower formations. Though these five waters differ considerably from each other in concentration, their average, as shown in lines A and B of the following table, gives a fair idea of their character:

Quality of waters from the rocks.

[Parts per million except as otherwise stated.]

	Number of analyses.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3)	Chlorine (Cl).	Total solids.
A	5	14	0.7	205	104	820	0.0	400	170	.....	1,570	3,890
B	5	.4	a.0	6.7	3.4	26.6	6.4	.....	5.5	0.0	51.0	.....
C	83	18	1.8	82	31	27	.0	341	70	1.0	19	466
D	169	18	.8	91	31	18	.0	306	76	2.8	47	467
E	83	4.4	a.4	19.6	7.4	6.5	40.2	.....	16.8	.2	4.5	.....
F	169	4.1	a.3	20.9	7.1	4.1	34.6	.....	17.5	.6	10.8	.....

a Fe_2O_3.

A. Average of analyses of water from lower limestones.
B. Percentage composition of anhydrous residue, computed from A.
C. Average of analyses of water from upper, or fresh-water, limestones.
D. Average of analyses of water from unconsolidated deposits.
E. Percentage composition of anhydrous residue, computed from C.
F. Percentage composition of anhydrous residue, computed from D.

The waters from the lower formations are very high in mineral content, and especially in chlorides, sulphates, alkalies, and calcium, being unfit for domestic or industrial use. These and other waters strongly polluted by them can readily be recognized by their chemical composition. The total solids exceed 700, the chlorides exceed 100, generally being 400 or 500, and there is commonly an odor of hydrogen sulphide. The large amount of magnesium in proportion to calcium is also distinctive. Such waters are encountered in drilling for gas and oil. The mixture of petroleum and salt water pumped from oil wells is run into tanks and allowed to settle, after which the water is drawn off and wasted, as a very highly mineralized liquid containing some petroleum and having a yellow to black color and an odor like a mixture of kerosene and rotten eggs. Part of it soaks into the ground near the pumping station, polluting the fresh-water supplies, and part runs into the streams, materially altering their composition. The problem of disposing of these oil-well wastes has

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been discussed by Bowman,[a] and it resolves itself into the practical question whether the ground waters or the streams shall be polluted. When wells drilled for oil are unproductive or when they cease to yield paying quantities of oil, the casings are often drawn out. Sometimes the casings are plugged above the salt water and split or partly withdrawn to permit entrance of water from the fresh-water limestones, so that the wells may yield potable supplies. In either case unless the well holes are carefully plugged above the "Trenton" limestone the salt water rises, mixes with the fresh water in the upper strata, and destroys sources of good supply, not only at that point, but also over an extensive area by infiltration. The danger of polluting fresh waters in this manner has repeatedly been referred to in the annual reports of the Indiana natural gas inspector, and state laws require proper plugging of abandoned holes.[b]

The mean composition of the water from the upper limestones, as computed from 83 analyses, is given in lines C and E of the foregoing table. Comparison with lines D and F draws attention to the great similarity between these waters and those of the drift. The limestone waters average lower in chlorides and higher in bicarbonates, a feature that makes them better for boiler use; many carry large amounts of iron, and the average iron content is more than twice that of the drift waters. Inspection of the individual analyses shows that the waters of the upper limestones differ locally from one another as much as the drift waters do, but that there is no tendency to increased mineral content toward the south. All these facts indicate that no general distinctions can be made between the quality of the waters from the drift and the quality of those from the fresh-water limestones, but that marked local differences may occur.

SURFACE WATER.

From August, 1906, to September, 1907, daily samples of water were collected from streams in or near the region under discussion and united in sets of ten consecutive samples, and analyses of the composites thus obtained permit computation of maximum, minimum, and average conditions. The results in detail have been published in Water-Supply Paper 236.[c] Samples of water from Wabash River at Logansport were collected by Mr. John Bender in midstream above the entrance of Eel River; lines A, B, and C in the following table give the mean, maximum, and minimum values, respectively, of the estimates. Wabash River was examined also at Vincennes, where Mr. L. J. Weisenberger collected samples from the waterworks

[a] Bowman, Isaiah, Disposal of oil-well wastes at Marion, Ind.: Water-Supply Paper U. S. Geol. Survey No. 113, 1905, p. 36.

[b] Thirty-second Ann. Rept. Indiana Dept. Geology and Nat. Res., 1907, pp. 590 et seq.

[c] Dole, R. B., The quality of surface waters in the United States, pt. 1: Water-Supply Paper U. S. Geol. Survey No. 236, 1910.

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ntake. The mean, maximum, and minimum values for the water at Vincennes are given in lines D, E, and F. At Indianapolis samples of water from West Fork of White River were taken in midstream under the direction of Mr. H. E. Jordan. Lines G, H, and I show the mean and the limits during the year for White River at Indianapolis. East Fork of White River was tested at Azalia, where samples were collected by Mr. L. E. Davis, and the summarized results are reported in lines J, K, and L. For comparison the average quality of the water of Lake Huron is given in line M, as computed from analyses of 12 monthly samples taken at Port Huron, Mich. The percentage composition of the anhydrous residues, computed from the mean quality of the same waters, is reported in lines N, O, P, Q, and R thus: Line N, percentage composition of the anhydrous residue of water from Wabash River at Logansport; line O, the same from Wabash River at Vincennes; P, West Fork of White River at Indianapolis; Q, East Fork of White River at Azalia; R, Lake Huron at Port Huron, Mich.

Quality of the surface waters.

[Parts per million, except as otherwise stated.]

	Turbidity.	Suspended matter.	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
A	132	117	14	0.23	82	35	142	0.0	234	79	5.9	292	807
B	900	802	38	1.2	133	77	478	7.9	317	138	18	960	1,940
C	Tr.	Tr.	5.0	Tr.	43	15	22	.0	116	42	.0	35	309
D	172	193	13	.24	61	22	25	.0	230	55	6.4	36	336
E	625	656	36	1.8	75	30	60	.0	264	73	18	104	504
F	15	18	3.0	Tr.	45	15	8.1	.0	147	37	1.1	8.3	209
G	39	38	14	.15	74	29	48	.0	291	58	6.1	78	450
H	235	124	27	.8	95	43	138	6.5	353	125	14	262	798
I	Tr.	Tr.	8.4	Tr.	48	17	14	.0	205	36	.5	13	245
J	52	48	15	.14	61	23	9.5	.0	276	30	5.6	3.1	279
K	245	240	29	1.2	70	29	16	12	320	40	12	8.0	334
L	3	Tr.	6.6	Tr.	42	15	5.2	.0	176	18	.5	1.3	196
M	Tr.	Tr.	12	.04	24	7.0	4.4	1.8	100	6.2	.4	2.6	108

PERCENTAGE COMPOSITION OF THE ANHYDROUS RESIDUES.

N	.....	.....	1.8	a.0	10.7	4.6	18.5	15.1	.....	10.3	.8	38.2	.....
O	.....	.....	3.9	a.1	18.4	6.6	7.5	34.1	.....	16.6	2.0	10.8	.....
P	.....	.....	3.1	a.0	16.4	6.4	10.7	31.8	.....	12.9	1.4	17.3	.....
Q	.....	.....	5.3	a.1	21.5	8.1	3.3	48.0	.....	10.6	2.0	1.1	.....
R	.....	.....	11.1	a.0	22.3	6.5	4.1	47.4	.....	5.8	.4	2.4	.....

a Fe_2O_3.

A, B, C. Wabash River at Logansport; analyses by W. M. Barr, H. S. Spaulding, and Walton Van Winkle.

D, E, F. Wabash River at Vincennes; analyses by W. M. Barr, H. S. Spaulding, and Walton Van Winkle.

G, H, I. West Fork of White River at Indianapolis; analyses by W. M. Barr, H. S. Spaulding, and Walton Van Winkle.

J, K, L. East Fork of White River at Azalia; analyses by W. M. Barr, H. S. Spaulding, Walton Van Winkle, R. B. Dole, Chase Palmer, and W. D. Collins.

M. Lake Huron at Port Huron, Mich.; analyses by R. B. Dole and M. G. Roberts.

N, O, P, Q, R. Percentage composition of the anhydrous residues computed from A, D, G, J, and M, respectively

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The most noticeable feature in the foregoing table is the unusually high mineral content of Wabash River at Logansport, which averages 807 parts per million, as compared with 466 and 467 for the ground waters of the same region; another noticeable feature is the great fluctuation in mineral content, which ranges from 309 to 1,940 parts per million. From line N it can be seen that the water is particularly high in alkalies and chlorides, and inspection of the individual analyses shows that high chlorides and alkalies are always coincident with high total solids. The chief reason for these phenomena is undoubtedly varying pollution by salt water from oil wells, as noted on page 261, because surface waters from regions similar to this in rainfall and rock formations have not this peculiar compostion. Wabash River and its southern tributaries above Logansport, the Mississinewa and the Salamonie (see Pl. I), receive a large amount of drainage from the oil belt, and physical evidence of this pollution, such as oil-stained and blackened vegetation, is encountered in the beds of streams. The scale formed in boilers using such water would be hard, and the water would also foam and corrode the boilers; at times of highest mineralization the water is unfit for boiler use. Though Vincennes is not in the region under discussion, analyses of the river water at that city have been introduced in order to show the improvement effected by dilution. The great change in concentration can be appreciated by comparing lines A and D. West Fork of White River at Indianapolis gives evidence of some oil-well drainage, but not to so great extent as Wabash River. (See lines G, H, and I.) The mean quality of this water is strikingly similar to that of the underground water. It differs principally in being higher in chlorides and alkalies and correspondingly lower in bicarbonates. As a source of industrial supply it is far superior to Wabash River at Logansport. East Fork of White River, sampled at Azalia, is not contaminated by oil wells, and its water is more or less typical of what the other rivers would be in their normal or unpolluted state and of streams in this section that do not receive oil-well drainage.

SUMMARY.

Figures representing the average chemical composition of the principal sources of water supply in this region are given in the following table. Line A shows the average of five analyses of waters from the lower limestones; line B, the average of 83 analyses of waters from the upper limestones; line C, the average of 169 analyses of waters from the unconsolidated deposits. The average mineral contents of the waters of the Wabash at Logansport and the White at Indianapolis are given in lines D and E, respectively.

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Average quality of waters in north-central Indiana.

[Parts per million.]

	Silica (SiO_2).	Iron (Fe).	Calcium (Ca).	Magnesium (Mg).	Sodium and potassium (Na+K).	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Nitrate radicle (NO_3).	Chlorine (Cl).	Total solids.
A	14	0.7	205	104	820	0.0	400	170	.....	1,570	3,890
B	18	1.8	82	31	27	.6	341	70	1.0	19	466
C	18	.8	91	31	18	.0	306	76	2.8	47	467
D	14	.2	82	35	142	.0	234	79	5.9	292	807
E	14	.2	74	29	46	.0	291	58	6.1	78	450

The chief points of interest in this table are the high mineralization of the waters from the lower limestones and from Wabash River and the great similarity in composition of the waters from the upper limestones, the drift, and White River. As stated in the previous paragraphs, however, it should be recognized that the river waters fluctuate a great deal in composition and that the waters of local wells differ greatly from one another.

FIELD ASSAYS.

The following table gives some field assays of water made in 1904 during a survey of industrial water conditions in Wabash River valley. The methods of assay and computation are outlined on pages 230 et seq. The tests at Greenfield were made by Herman Stabler; the others were made by R. B. Dole. These results, though necessarily cruder and less reliable than laboratory analyses, serve to amplify and to corroborate the statements and conclusions noted in the preceding pages and indicate a field of practical usefulness for assays of this nature.

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Field assays of waters in north-central Indiana.

[Parts per million.]

SURFACE WATERS.

No.	Location.	Date (1904).	Color.	Odor.	Turbidity.	Iron (Fe).	Chlorine (Cl).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Total hardness as $CaCO_3$.	Estimated incrustants.	Classification for boiler use.
....	Blue River at Columbia City	June 15	60	3 v	a 12	0.5	9	293	60	205	265	Fair.
....	Brandywine Creek at Greenfield	Apr. 15	25	2 v	a 10	1.0	5	284	a 10	275	264	Do.
....	Center Lake at Warsaw	June 17	40	2 v	a 5	Tr.	16	174	60	261	245	Good.
....	Deer Creek at Delphi	July 2	40	3 v	a 15	1.0	4	259	a 10	234	232	Do.
....	Eel River at Logansport	June 29	25	2 v	a 10	0.5	7	278	a 25	194	229	Do.
....	Manitou Lake at Rochester	June 23	56	4 v	a 14	.....	22	140	a 20	161	152	Do.
....	Mississinewa River at Peru	...do....	96	2 M+2o	a 20	1.5	130	178	55	208	216	Fair.
....	Salamonie River at Lagro	June 20	25	3 M	50	4	930	213	115	395	366	Bad.
....	Tippecanoe River at Rochester	June 23	56	3 M	0	3	17	229	a 10	141	174	Good.
....	Tippecanoe River at Winamac	July 3	40	2 v	0	2.5	4	235	a 20	194	207	Do.
....	Tippecanoe River at Monticello	July 2	40	2 e	a 20	1.5	4	210	a 10	154	172	Do.
....	Wabash River at Lagro	June 20	40	2 e	80	2.8	172	202	90	261	278	Poor.
....	Wabash River at Logansport	June 30	60	4 v	55	2.5	186	213	75	234	260	Do.
....	Wabash River at Delphi	July 1	60	3 e	50	4	115	221	65	234	254	Do.
....	Wildcat Creek at Kokomo	July 7	56	4 e+2 M	390	Tr.	4	142	a 5	114	120	Good.
....	Winona Lake at Warsaw	June 17	56	2 v	a 5	Tr.	14	175	35	215	206	Do.

GROUND WATERS.

1	Delphi	July 1	0	0	0	3	4	295	a 10	234	248	Good.
2	.....do	...do....	0	0	0	3	70	449	330	(b)	835	Bad.
3	.....do	...do....	40	5 H_2S +5o	a 10	3	.....	822	Tr.	.....	679	Do.
4	.....do	July 2	0	0	0	2.5	156	480	220	.....	711	Do.
5	Greenfield	Apr. 15	.....	0	0	2.5	4	363	Tr.	332	316	Fair.
6	.....do	...do....	.....	0	0	Tr.	39	384	45	416	399	Poor.
7	.....do	...do....	0	0	0	3.5	12	379	45	402	389	Do.
8	Kokomo	July 7	0	2 e	0	3	12	330	85	261	326	Fair.
9	.....do	...do....	.....	5 H_2S	0	Tr.	50	357	Tr.	275	285	Poor.
10	.....do	...do....	0	0	0	4	4	373	Tr.	248	278	Fair.
11	.....do	July 8	0	2 e	0	11	17	260	980	529	1,069	Bad.
12	.....do	...do....	0	2 e	a 10	3	9	384	Tr.	315	316	Fair.
13	Logansport	June 29	0	2 H_2S	0	0.5	17	352	40	275	312	Poor.
14	.....do	June 30	0	5 H_2S	0	1.5	514	375	90	355	394	Bad.

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15	Peru	June 23	0	0	0	1.0	67	323	70	234	300	Fair.
16	.....do.....	.....do.....	0	0	0	Tr.	50	369	40	315	339	Do.
17	.....do.....	.....do.....	0	0	0	Tr.	24	339	45	315	329	Do.
18	Rich Valley	July 21	40	2 o	a 20	2.5	582	253	95	422	384	Bad.
19	Rochester	July 24	0	0	0	.5	19	316	a 20	288	288	Fair.
20	.....do.....	.....do.....	0	0	0	2.5	9	323	Tr.	248	258	Do.
21	Wabash	July 21	0	1 H_2S	a 5	3	2	356	a 5	301	302	Do.
22	.....do.....	.....do.....	0	0	0	1.5	9	300	a 10	.....	265	Good.
23	.....do.....	.....do.....	0	0	0	2.5	111	358	75	328	366	Poor.
24	.....do.....	.....do.....	0	0	a 5	1.0	42	346	120	315	386	Do.
25	.....do.....	.....do.....	0	0	0	2.5	127	402	185	440	518	Bad.
26	Warsaw	July 17	0	0	a 10	3	4	307	Tr.	261	258	Good.
27	.....do.....	.....do.....	0	0	0	Tr.	6	269	a 10	221	230	Do.
28	.....do.....	July 18	0	3 H_2S	a 5	3	4	323	Tr.	234	250	Poor.

a Estimated.

b More than 500.

1. Springs 3 miles from city used for city supply; water from gravel.
2. Well of Matthew Julius in North street. Dug and bored 54 feet deep; water from gravel.
3. Flowing well in rock about 900 feet deep at city pumping station; chlorine high.
4. Well of Mr. Swigman, 16 feet deep in gravel.
5. City water supply from deep wells in gravel.
6. Well at corner of East Main and North Pratt streets, 14 feet deep in gravel.
7. Well at corner of East Main and North Pratt streets, 22 feet deep in gravel.
8. One of city wells in limestone about 130 feet deep.
9. Flowing well in the city park; water from the rock.
10. Well in city park, penetrating limestone.
11. Gravel well 48 feet deep in Crown Point cemetery.
12. Well of L. E. Collier near city limits; 89 feet deep; water from limestone.
13. Gravel well in Spencer Park; 35 feet deep.
14. Well about 600 feet deep at city waterworks and electric-ligh tplant.
15. City well No. 17; water from limestone.
16. Spring in edge of bluff at plant of Peru Brewing Company.
17. Well at plant of Peru Brewing Company; well 206 feet in rock.
18. Large dug well in river bottom at power house of Union Traction Company. It is understood that part of this water came by a tile pipe from Wabash River.
19. Well on Pearl street near Lake Erie and Western Railroad tracks; 30 feet deep in gravel.
20. Well 405 feet deep at the court-house corner; enters limestone.
21. One of city wells in valley of Treaty Creek; 50 feet deep in gravel.
22. Well 11 feet deep in gravel used to furnish water for Cleveland, Cincinnati, Chicago and St. Louis Railway locomotives.
23. Wells sunk 24 to 30 feet in river bottom of alluvium at plant of United Boxboard and Paper Company.
24. Well in rock about 180 feet deep in court-house square.
25. Dug well in gravel 24 feet deep at 122 East Maple street.
26. Well in sand 46 feet deep at Winona Park.
27. Flowing well in sand 22 feet deep at Winona Park.
28. Well in rock on east shore of Pike Lake; depth unknown.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 255

UNDERGROUND WATERS FOR FARM USE

BY

MYRON L. FULLER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1910

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UNDERGROUND WATERS FOR FARM USE.

By MYRON L. FULLER.

INTRODUCTION.

The agricultural lands of the United States, constituting, as they do, almost the whole of the eastern half of the country as well as a very large proportion of the habitable areas in the West, deserve to have especial attention paid to their needs. Of these needs few are greater than that of purer water supplies. Farms, which are generally remote from towns, cities, or other areas of congested population, seem to be almost ideally situated for obtaining pure and wholesome water. In reality, however, polluted water is exceedingly common on them (fig. 1) and typhoid-fever rates are usually

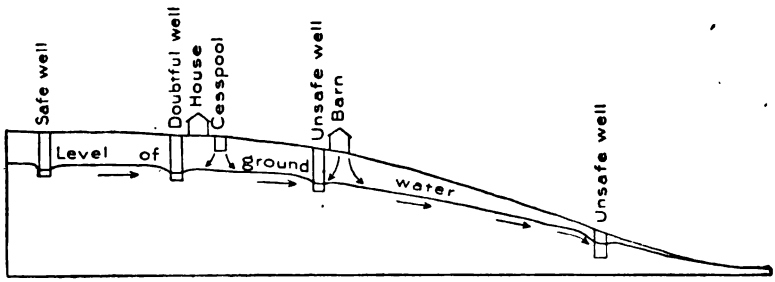

FIGURE 1.—Diagram showing ordinary location of farm well.

greater in country districts than in cities. Typhoid fever is now almost universally believed to be transmitted solely through drink or food taken into the stomach, and is especially liable to be communicated by polluted waters obtained from shallow wells near spots where the discharges of typhoid patients have been thrown upon the ground and subsequently carried down through the soil and into the wells, and it is doubtless principally this fact that makes the disease so common in farming regions.

Many of the failures to protect adequately the water supplies used for drinking arise from a lack of knowledge of the manner in which waters circulate through the ground and of the ways in which they may become polluted. Information on these subjects must needs

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be of value, and it is with the object of supplying this information, in so far as it may be possible to furnish it in a brief paper, that the present report has been prepared.

SOURCES OF WATER SUPPLY.

WATER-BEARING FORMATIONS.

All known rocks contain more or less water, and though many of them will not yield it in useful quantities to wells all must be considered in a discussion of water-bearing formations. Many rocks are familiar to everyone, at least by name; others are less widely known and may be restricted to very small areas. The classes of rocks commonly recognized and the definitions of the simpler varieties are given below for the benefit of those not familiar with the terms in use.

CLASSES OF ROCKS.

In a simple classification rocks may be grouped into three divisions: (1) Sedimentary, (2) igneous, and (3) metamorphic.

Sedimentary rocks (Pl. I) are formed either of fragments worn from older rocks by the action of rain, wind, frost, etc., and carried by water, wind, or glaciers until deposited as beds of clay, sand, gravel, marl, loess, etc.; or of the remains of corals or of shellfish, such as oysters and clams. When first deposited the materials are loose and unconsolidated, but gradually they become hardened and cemented together, especially when covered by later beds, and eventually form solid rocks. These fragments or grains are commonly rounded, and their form may therefore help to distinguish them from igneous rocks, which may have corners or angles or may include angular crystals.

Igneous rocks (Pl. II, *B*) may have come from the earth's interior in a molten state and have been forced into or through the rocks above them or may have overflowed as lava beds at the surface. They are generally made up of or at least include angular crystals, which may be recognized by their glistening faces, a feature that is not usually possessed by sedimentary rocks. Many of them are banded and most of them are irregular in mass and occurrence; locally they may contain vividly colored patches and bands.

Sedimentary and igneous rocks in many places have been subjected to heat and pressure after their deposition. This action may have further hardened them or have so greatly changed them that their original character can scarcely be determined. Rocks thus changed are known as metamorphic rocks (Pl. II, *A*). Mica schist and marble are typical examples. As a rule they exhibit a bedded or banded structure.

Rocks of all of these types occur the world over, and those of one locality may be indistinguishable from those of another. Notwith-

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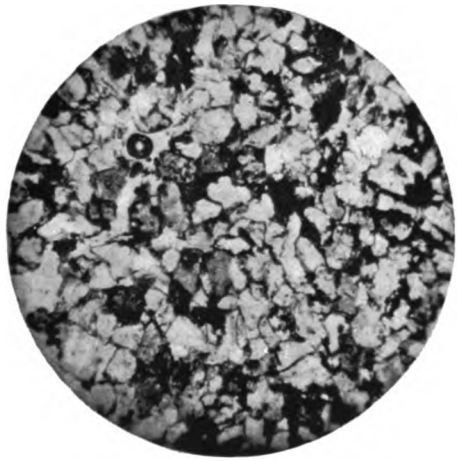

A. VIEW OF SEDIMENTARY ROCK UNDER MICROSCOPE, SHOWING PORE SPACES (DARK).

B. WATER-BEARING FORMATIONS: BEDDED SEDIMENTARY ROCKS.

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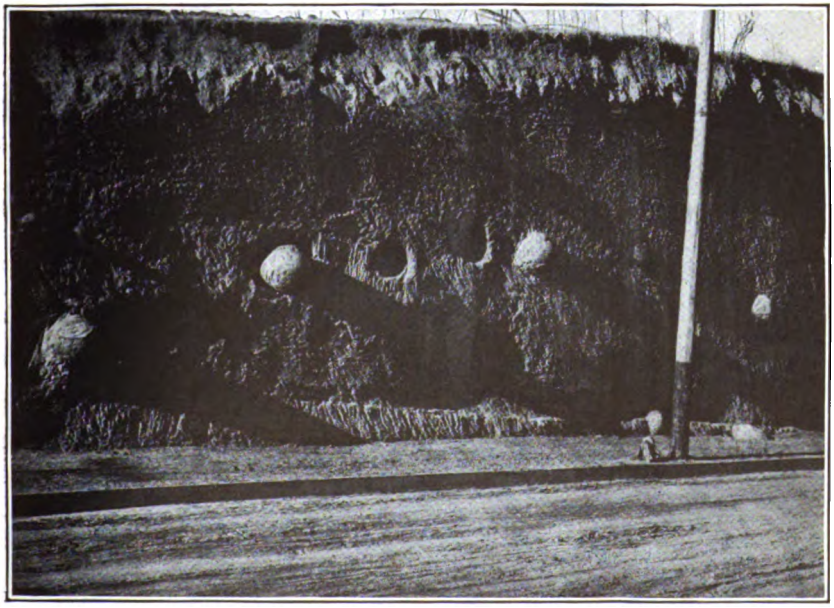
A. ROCK CONTAINING FOSSIL SHELLS (SHELL MARL).



B. CONCRETIONS IN SANDSTONE.

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standing these similarities, they may have been formed under very different conditions and at periods thousands or even millions of years apart. Resemblances between rocks do not, therefore, mean that they were formed at the same time or will yield the same products, such as coal or oil or water.

DEFINITIONS OF ROCKS.

Simple definitions of the more common rocks are given below. Complete descriptions and definitions of rarer varieties may be found in any text-book on geology.

UNCONSOLIDATED SEDIMENTARY DEPOSITS.

Gravel, sand, and clay are made up respectively of pebbles, sand grains, and fine silts worn from older rocks and redeposited in their present form.

Alluvium is a general term for gravels, sands, and clays, or mixtures of these that have been deposited by streams.

Chalk is a soft white earthy form of limestone.

Marl is a clay with much intermingled calcareous material.

Till is a heterogeneous mixture of clay, sand, pebbles, and bowlders deposited by glaciers.

Hardpan is a general term which may be applied to any bed which is considerably harder than those with which it is associated. It is often applied to till, to tough clays, or to partly cemented sand or clay beds.

CONSOLIDATED SEDIMENTARY ROCKS.

Conglomerate (Pl. III, *B*) is a consolidated gravel.

Sandstone (Pl. III, *A*) is a consolidated sand. It is said to be massive if there are few bedding planes, and shaly if it splits into plates.

Quartzite is a sandstone in which the spaces between the grains have been filled with a hard cement (silica), forming an excessively hard rock.

Shale is consolidated clay; a soft, fine-grained rock which tends to split into thin plates. It is sometimes improperly called soapstone.

Limestone is composed mainly of carbonate of lime, but often contains sand and other impurities, and may be very hard. Not infrequently it contains many shells or is made up entirely of them. It can be most readily recognized by the bubbling which takes place when it is touched with hydrochloric (muriatic) acid. In varieties high in magnesia and in magnesium carbonate, or dolomite, hot, strong muriatic acid is necessary to produce this action.

Tuff is any sedimentary rock that is made up entirely or almost entirely of fresh fragments of volcanic rocks.

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Concretions (Pl. IV, *B*) are hard, lumplike masses within the rock. They should not be confounded with real bowlders, from which, as a rule, they may readily be distinguished, because they consist of nearly the same material as that in which they are embedded.

IGNEOUS ROCKS.

Granite is a wholly crystalline rock, composed of quartz, feldspar, and other light-colored minerals.

Diorite, gabbro, and diabase are crystalline rocks similar to granite, but with less quartz and with dark-colored feldspars.

Volcanic rocks, lavas, etc., are rocks that have been emitted in a molten state from volcanoes.

Trap is a widely distributed, compact, very dark colored variety of volcanic rock. Technically it is a basalt or diabase, and these terms are in common use.

METAMORPHIC AND CRYSTALLINE ROCKS.

Slate is like shale, but harder; it splits into thin plates which may or may not coincide with the bedding. The tendency to split is not often recognized in drilling. Roofing slate is a familiar example.

Marble is a crystalline limestone, and gives the same reaction with acid as limestone, marl, and chalk.

True soapstone is a soft, even-grained, greasy-feeling rock composed of the mineral talc, but the term is incorrectly applied to any soft, greasy-feeling rock, such as soft shale.

Schist is a more or less crystalline rock which has a laminated structure, due to the flat crystals of mica or other minerals of which it is composed.

Gneiss is similar to granite in composition, but has a less perfect crystalline structure and a banded structure due to the linear arrangement of its crystals.

FOSSILS.

In many sedimentary rocks remains of animals and plants are found. (See Pl. IV, *A*.) These generally consist of portions or impressions of shells, skeletons, or leaves, and are known as fossils. A bed may be recognized and determined by such remains, which are therefore of great importance in geologic work. In the oldest rocks only low organisms, such as shellfish, are found, but in later rocks, fishes, reptiles, and mammals progressively appear, while vegetation shows a corresponding change of its predominant types from microscopic forms to the forest trees of to-day.

FORMATIONS.

A rock bed or a succession of beds that are uniform in character throughout a considerable area is termed a formation and is given

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a geographic name derived from some place or feature in the area where it typically occurs, such as Trenton limestone. The correct identification of formations is very important in underground-water studies, as by this means the structure and position of water-bearing beds is worked out.

STRUCTURES OF ROCKS.

When deposited, sedimentary beds are nearly horizontal, but they may be subsequently thrown into inclined positions, or bent into arches or troughs, or broken and displaced. It is rather unusual, in fact, to find in the interior of the continents any sedimentary beds which have not been tilted, folded, or otherwise disturbed, at least slightly. Some of the terms used to designate the structures that result from these disturbances are as follows:

An anticline (Pl. V, *A*) is the arched part of a rock fold.

A syncline (Pl. V, *B*) is the trough of a rock fold.

A fault is a rock fracture the sides of which have been displaced from their original position with reference to one another.

The dip of a bed is the angle by which it deviates from the horizontal plane.

Strike is the compass direction of the intersection of an inclined bed with a horizontal surface.

A joint is a plane of fracture or crack in a rock the sides of which have not been materially displaced with reference to one another.

Cleavage planes are minor planes traversing a rock, as a rule in one direction, and in many rocks are simply lines along which the rock tends to split rather than actual fractures. They are commonly due to the action of pressure on compact rocks.

Foliation and schistosity are planes of easy splitting, due to the arrangement of the minerals of the rock with their elongated directions parallel with one another.

OCCURRENCE OF WATER.

All rocks contain more or less water, which either occupies perceptible cavities in the rock or occurs within the minute pores. The water in the pores is given up readily only by the coarser rocks, such as sandstones, the fine-grained rocks yielding very little of such water when penetrated by the drill. Water found in these rocks usually comes from the joint, fault, or foliation planes. The conditions of the occurrence of water in various rocks differ widely.

SAND AND GRAVEL.

Sands and gravels are very porous. Thirty per cent of the volume of some sand or gravel deposits are made up of free space between the grains. In such material the whole mass below ground-water level is

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saturated, and when penetrated by wells yields copious supplies. The waters of such deposits are, as a rule, of good quality, but some are mineralized, having dissolved material from the more soluble fragments and particles that constitute the deposits.

The cheapest and best method of obtaining small supplies of water from sands and fine gravels is by driven wells, which can be sunk quickly and at slight cost. It is difficult, however, to exclude very fine sand or quicksand from pipes, quicksand frequently penetrating the well and clogging the pipe or ruining the pump. Because of the readiness with which sands and gravels yield their water, wells sunk close together in such deposits may affect one another, the well that draws from the sand at the lowest level taking the water from the higher wells. The readiness of movement of the water also causes important fluctuations of the water in the ground, the water level rising and falling rapidly with the beginning and cessation of rain. To obtain permanent supplies, wells should penetrate to a level below that of the ground-water surface in the driest seasons. (See fig. 2.)

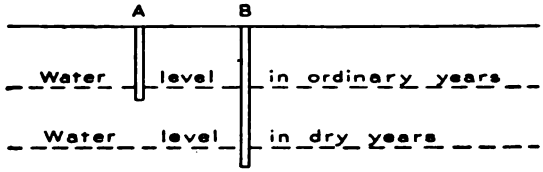

FIGURE 2.—Diagram showing relation between depth and permanence of wells.—A, Well sunk to ordinary water level, but failing at times of drought; B, well sunk to level of water in dry years and never failing.

CLAY.

Clay usually contains large quantities of water, but its pore spaces are so fine or small that water soaks into it or out of it so slowly that it is impervious in the sense that little or none of that which it contains can be utilized as a source of supply. Considerable amounts are frequently reported in clays, but they usually come from more or less sandy layers. In some places sand that approaches clay in fineness and that is sometimes mistaken for clay yields considerable amounts of water. Clay is of the greatest importance, however, not as a water-

FIGURE 3.—Diagram showing action of clays or shales in confining water in sand or sandstone.

bearer, but as a confining layer which prevents the water from escaping, or as a layer collecting the water from overlying porous beds and bringing it to the surface. (See fig. 3.)

When, because of the absence of other sources, it is necessary to obtain supplies from clay, a well sunk should be of as large diameter possible and should be continued far enough beneath the point at

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which water is obtained to insure ample storage capacity. (See fig. 4.) Dug wells are usually most satisfactory where the clay is near the surface, but such wells should be carefully covered and guarded from all sources of pollution.

TILL.

Till is a heterogeneous mixture of clay, sand, gravel, and bowlders, deposited by glaciers. In texture it varies from porous to impervious, according to whether sand or clay predominates. It is, as a rule, not definitely bedded. The water that it contains generally occurs in small more or less tubular channels a few inches in diameter, but here and there is distributed through interstratified sandy beds.

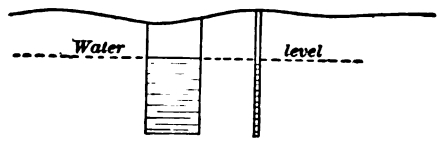

FIGURE 4.—Relative size and storage capacity of dug and drilled wells.

In the aggregate, till yields a large amount of water, being the prevailing source of supply in the rural districts at a great number of points throughout the northern portion of the country. Because of the occurrence of the water in definite channels, however, the success of wells in till varies greatly. In general, wells of large diameter give the best success. Figure 4 represents two wells of the same depth, one dug and one bored. It will be seen that in the dug well not only is a larger amount of material encountered in cross section, but the area of surface from which water can enter is many times greater than in the bored well. The open well is also of larger storage capacity, and can be employed to utilize small supplies—supplies that would be insufficient to furnish enough water to a bored well.

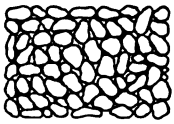

FIGURE 5.—Arrangement of grains in sands and sandstones with intervening pores open and capable of holding water.

SANDSTONE, CONGLOMERATE, AND QUARTZITE.

Sandstone is, on the whole, the best water bearer of the solid rocks. Under the most favorable conditions sandstone is saturated throughout its extent below the regular ground-water level, and wherever it is struck by the drill within these limits (see fig. 5) it yields water freely, as a rule, although some of the finer-grained sandstones yield it less readily. In quality the water in sandstones is, as a rule, better than that in any other material except sand and gravel. Drilled wells are used to recover water from sandstone except where it is very near the surface.

Some conglomerates furnish considerable water, although, as a rule, the absorptive power of conglomerates is not so great as that of sandstones, and they are much less frequently encountered.

Quartzite is a sandstone in which the spaces between the grains have been filled by hard siliceous matter. Because of the filling of

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the pores by this material there is relatively little chance for the water to enter, and the rocks are not commonly an important source of supply. (See fig. 6.)

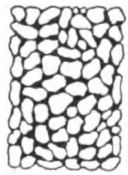

FIGURE 6.—Arrangement of grains in sands and sandstones with intervening pores filled with mineral matter preventing the absorption of water.

SLATE.

Slate, like clay, is a poor water bearer but may yield water from crevices along bedding, joint, and cleavage planes. Its most important use with reference to water supply, is as a confining layer to prevent the escape of water from porous sandstones which may be interbedded with it. The waters in slate are reached by deep wells and are generally uncontaminated but are not uncommonly mineralized.

LIMESTONE.

Waters occur in limestone mainly in open channels (Pl. VI, *B*), caverns, etc., dissolved in the rock by the water itself. The water originally probably followed joint or bedding planes which were gradually enlarged by solution into the caverns that now exist.

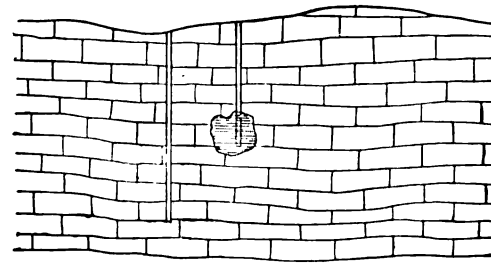

FIGURE 7.—Difference in conditions of adjacent wells in limestone.

The occurrence of caverns and passages within the limestone is very irregular, and their location can seldom be predicted. Most deep wells which are drilled in limestone regions, however, encounter one or more such passages at a relatively slight distance below the surface. Wells in limestone, even where only a few feet apart, may nevertheless obtain very different results, as a difference of a foot or two may mean the missing of a certain channel, as indicated in figure 7. The waters in limestone are generally hard but are not commonly otherwise mineralized.

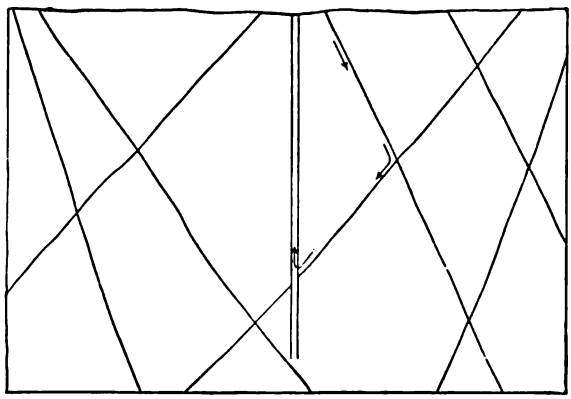

FIGURE 8.—Wells in jointed rocks.

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GRANITE, GNEISS, AND SCHIST.

Granites and gneisses are very dense and possess very small pore spaces, and most of these rocks hold very little water. In schists, however, considerable water often penetrates along the foliation planes and is held by the rock, but such water is given up very slowly and is not important as a source of supply.

It is along the joints in these rocks that the largest supplies are obtained. (See fig. 8.) These joints are most common near the surface and diminish in number and in definiteness as the depth increases. For this reason the water supplies from such rocks, if obtained at all, are usually found within 200 or 300 feet of the surface. It is generally useless to go deeper than 500 feet for waters in these crystalline rocks, although in some places, as at Atlanta, Ga., water is said to have been obtained at depths as great as 1,600 feet.

USE OF THE DIVINING ROD.

Numerous mechanical devices have been proposed for detecting the presence of underground water, ranging in complexity from the simple forked branch of witch-hazel, peach, or other wood to more or less elaborate mechanical or electric contrivances. Many of the operators of these devices, especially those who use the home-cut forked branch, are entirely honest in the belief that the working of the rod is influenced by agencies —usually regarded as electric currents following underground streams of water—that are entirely independent of their own bodies, and many uneducated people have implicit faith in their ability to locate underground water in this way. In experiments with a rod of this type the writer found that at certain points it seemed to turn downward independent of his will, but more complete tests showed that this downturning resulted from slight and, until watched for, unconscious muscular action, the effects of which were communicated through the arms and wrists to the rod. No movement of the rod from causes outside of the body could be detected and it soon became obvious that the view held by other men of science is correct—that the operation of the "divining rod" is generally due to unconscious movements of the body or of the muscles of the hand. The experiments made show that these movements happen most frequently at places where the operator's experience has led him to believe that water may be found.

The uselessness of the divining rod is indicated by the facts that it may be worked at will by the operator, that he fails to detect strong water current in tunnels and other channels that afford no surface indications of water, and that his locations in limestone regions where water flows in well-defined channels are no more successful than those dependent on mere guesses. In fact, its operators are successful

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only in regions in which ground water occurs in a definite sheet in porous material or in more or less clayey deposits, such as pebbly clay or till. In such regions few failures can occur, for wells can get water almost anywhere. Ground water occurs under certain definite conditions, and just as surface streams may be expected wherever there is a valley, so ground water may be found where certain rocks and conditions exist. No appliance, either mechanical or electrical, has yet been devised that will detect water in places where plain common sense will not show its presence just as well. The only advantage of employing a "water witch," as the operator of the divining rod is sometimes called, is that crudely skilled services are thus occasionally obtained, since the men so employed, if endowed with any natural shrewdness, become through their experience in locating wells better observers of the occurrence and movements of ground water than the average person.

RELATIVE SAFETY OF DIFFERENT MATERIALS.

The safety of the water supplies used for drinking purposes when near any source of pollution, depends principally upon the character of the openings through which the water passes, and this in turn depends on the nature of the materials in which the water occurs or through which it has passed.

Sands and gravels.—In passing downward through sand surface waters are subjected to natural filtration, especially in the finer varieties, and the substances with which they may have originally been polluted are frequently removed, at least in part. In coarser sands and in gravel the water passes downward more rapidly, the conditions are less favorable for filtration, and the water may remain polluted. In general, however, waters from sands and gravels, if taken from a considerable distance below the surface, are safe to use.

Clay.—The waters of clays, because of the fineness of the material, come into contact with relatively large amounts of mineral matter and frequently become mineralized, lime and salt being the most common substances dissolved; as a rule, however, owing to the filtration of the waters through the exceedingly fine material and the slowness with which polluting matter progresses and the slight distance to which it reaches in such material, they are free from contamination.

Till.—The water of till is generally uncontaminated because of the natural filtration due to its slow downward penetration through the clay and sand of which the till is largely composed. In some places, however, springs have formed more or less definite tubular channels through the material, and if such a channel leads from a cesspool or similar source of pollution the water becomes highly charged with matter dangerous to the health. Once contaminated it is likely to

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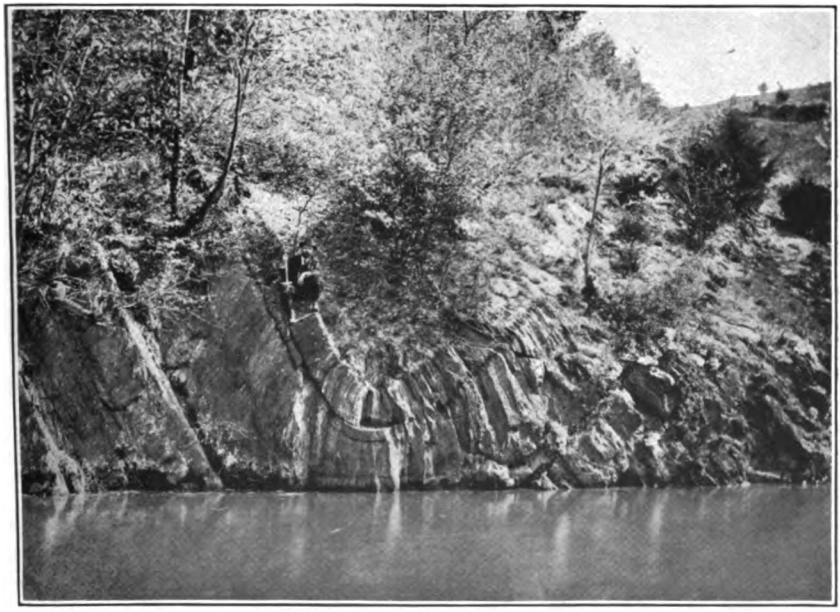
A. ANTICLINE.



B. SYNCLINE.

ROCK STRUCTURES.

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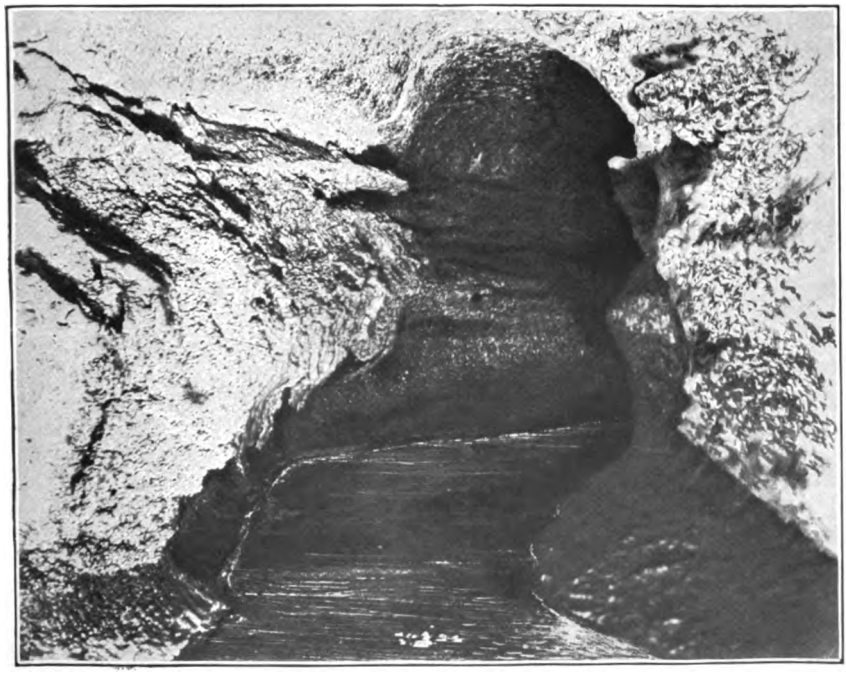
A. POLLUTION OF GROUND WATER: SEWAGE DISCHARGING INTO SINK-HOLE.



B. OCCURRENCE OF GROUND WATER: LIMESTONE CHANNEL.

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continue so for long distances, as little natural filtration takes place, because of the nature of the channel. (See fig. 9.) The water from till should be thoroughly tested by a bacteriologist if there seems any likelihood of contamination.

Sandstone, conglomerate, and quartzite.—The waters in these materials are very rarely polluted, owing in the more porous varieties to the natural filtration and in the compact varieties to the difficulty with which contaminated waters penetrate them. In quartzitic rock,

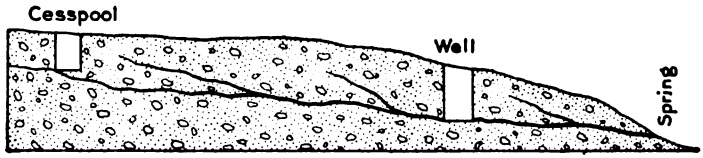

FIGURE 9.—Diagram showing possibility of pollution of wells and springs by material conducted from cesspool through tubular water passages in till.

however, joint fractures may admit both water and polluting materials from the surface.

Shale and slate.—Like the waters of clays and for the same reasons, the waters of slates and shales suffer very little pollution.

Limestone.—In the vicinity of buildings or settlements the waters of limestone are frequently contaminated and unfit for use. This is not because of the amount of lime dissolved, but because of the fact that the water falling on the surface as rain often plunges directly through basins or sinks into the underground channels instead of slowly filtering downward through the soil and into the rock, as in most other materials. This water carries with it the impurities washed or otherwise brought to the sink and bears them along

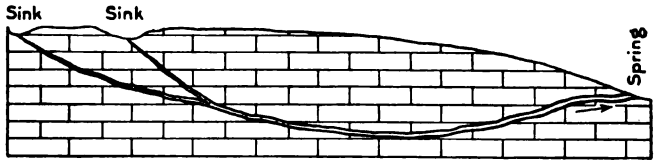

FIGURE 10.—Limestone passage connected with sinks.

through underground passages to distant points. (See fig. 10.) It is a common practice to dump manure, sewage, and other refuse into these sinks, regardless of the fact that it will eventually enter the underground water body. Fortunately in the United States many limestone regions are thinly inhabited, so the danger is not perhaps so widespread here as elsewhere. When springs which have been guarded from surface wash become muddy after a rain it is safe to assume that surface impurities have had access to the ground

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water through the sinks or otherwise, and such waters should be avoided.

Granite, gneiss, and schist.—The joints in these rocks generally occur in complex systems of intersecting planes, and it is possible for polluted water starting very near the mouth of the well to pass in a zigzag course downward along the joints, finally reaching the well at a depth of many hundred feet (fig. 8); such was the case in a well at Atlanta, Ga., which finally had to be abandoned. For this reason wells drilled in broken and jointed igneous rocks in cities and other thickly populated regions are liable to pollution. Waters from such wells, if they are to be used for drinking, should be tested occasionally to determine whether they are polluted or not.

COMMON SOURCES OF WATER.

The sources of the water used on the farm are numerous—lakes, streams, springs, drilled, bored, driven, and dug wells, and cisterns all being extensively used, although the water from lakes and streams is generally used only for stock. Each of these sources under some conditions may yield entirely safe and satisfactory supplies, while under other conditions certain of them may be a constant menace to the health.

Lakes and ponds.—The waters of lakes and of large ponds, which here include all fresh-water bodies half a mile or more in diameter, are generally good, except when they are polluted by the drainage or sewage from cities or large towns on their shores or on the lower courses of tributary streams. In ponds and in the smaller lakes such pollution may render the entire body of water unsafe for domestic use.

Sunlight, however, has a marked purifying action, tending to destroy the dangerous germs, while, under the action of winds, wave action and circulation are induced in the water, favoring aeration (mixture with air), which, by oxidation, likewise helps to remove the dangerous impurities. At the same time the heavier sediment brought in by the streams is constantly settling to the bottom. As a result of all these processes of purification, the water which entered in a polluted state may at last become so changed that on leaving the lake at its outlet it is both palatable and wholesome.

So rapidly has this purifying action been supposed to take place that before the construction of the Chicago drainage canal it was thought safe by some to draw the supply of the city from Lake Michigan at a distance of only a few miles offshore. Experience proved, however, that while noticeable pollution was confined to a relatively small portion of the lake, and while normally the city supply was fairly safe, it was, nevertheless, under certain conditions of wind and currents, liable to pollution. It was thus necessary either to remove the intake to a point several miles farther away or to divert the sew-

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age from the lake. The Chicago drainage canal, by diverting the sewage, has done much to solve the problem.

Natural lakes are confined almost wholly to the northern portion of the country, where they form a belt extending from eastern North Dakota to eastern Maine. In this belt, besides the Great Lakes, there are tens of thousands of smaller lakes, Minnesota alone having several thousand.

Most of the lakes, especially the smaller ones, are in thinly inhabited regions and afford supplies of high purity. Unfortunately, however, owing to the fact that farmhouses, even if in the vicinity of lakes are usually placed on high ground at some distance from the water it is necessary, if the lake is used as a source of supply, to haul the water required for domestic purposes. Because of the inconvenience thereby entailed few of the lakes are used, although they constitute ideal supplies for horses and cattle and furnish pure water to those cities which lie within convenient piping distance from them.

In the smaller water bodies, varying from mere pools to lakelets several acres in extent, there is less dilution of the impurities washed into them than in the lakes and large ponds, and even where there are both an inlet and an outlet there is often a tendency for the main current to pass directly from the inlet to the outlet without mixing with the water as a whole, the greater part of the lake thus remaining relatively stagnant. The entrance of a very slight amount of polluting matter into such waters may dangerously affect their quality.

Owing to the slight circulation in these small bodies of water decaying leaves and twigs will frequently accumulate and, together with the growth of water organisms, will give the water an amber or even a dark-brownish color and a noticeable taste. Such coloration does not make the water dangerous any more than the green algous slime that collects on the surface (most of which is perfectly innocent), but both are indications of stagnant conditions that are repugnant to the mind and may mask dangerous impurities. On the bottoms of ponds of this sort there are usually accumulations of decaying vegetable matter mixed with silt, which are very objectionable in water to be used for drinking. It is such accumulations which give off the bubbles of gas that may be seen rising to the surface when the bottom is disturbed.

Not all small ponds, however, should be condemned because of their size. Many are fed by springs, are free from pollution, and contain water as clear and cool as could be desired. Such ponds may be used to advantage for domestic supplies, although as the farmhouses are usually situated at a distance from the water they are seldom used except for watering stock.

In some of the prairie and semidesert regions, where streams are relatively few in number or even absent over large areas and where

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wells do not yield sufficient supplies, water is often obtained from artificial ponds. These are usually formed by throwing up a low embankment across some shallow depression or flood-water channel, behind which the rain water or the brief flood flow accumulates. Such reservoirs are commonly but a few rods in diameter and a few feet in depth. As a consequence the water becomes heated in summer, is usually kept constantly muddy by the movements of stock, and is highly polluted by them. (See Pl. VII, *B*.) As numerous animal diseases may be communicated through drinking water, small ponds of this sort may become a source of great danger.

Many of the water pockets or "tanks" of the deserts, in part natural and in part artificial, are also entirely unsafe even for stock use, although as they constitute the only source of water in many regions such use is unavoidable. In fact, the upbuilding of considerable grazing industries has been made possible by such water pockets in otherwise waterless regions.

Streams.—Over a large part of the country streams and rivers form the most available sources of supply, and in thinly settled regions they are usually free from contamination, although even here a tan-bark plant or sawmill may lessen the desirability of the water for domestic purposes.

Mines, especially coal mines, may likewise discharge their drainage of acid and otherwise polluted waters into the streams with similar effects, but the most common source of pollution is the sewage from towns and cities. In fact, practically all the larger streams, and even many of the smaller ones, are highly polluted by such sewage or by refuse from various manufacturing plants. It is true that such streams become gradually purified and under ordinary conditions may be fairly safe, but the periodic outbreaks of typhoid fever that occur among the users of their water are sufficient to indicate the imperfect nature of this purification.

Large cities without other accessible sources will doubtless continue to use river waters, but these waters are now, as a rule, scientifically filtered before distribution. On most farms, however, other and safer sources are available, and stream waters which are known to have received drainage or sewage from any source should not be used for drinking. (See Pl. VII, *A*.) In the larger streams the pollution is rarely high, and many of them will afford satisfactory supplies for stock.

Springs.—Springs usually form an ideal source of farm supply. Occurring in great abundance in many of the thinly settled regions and coming from considerable depths within the rock or filtering from sand or gravel, they are almost always free from pollution except where buildings are situated on the hillsides above them or where surface wash is allowed to enter them.

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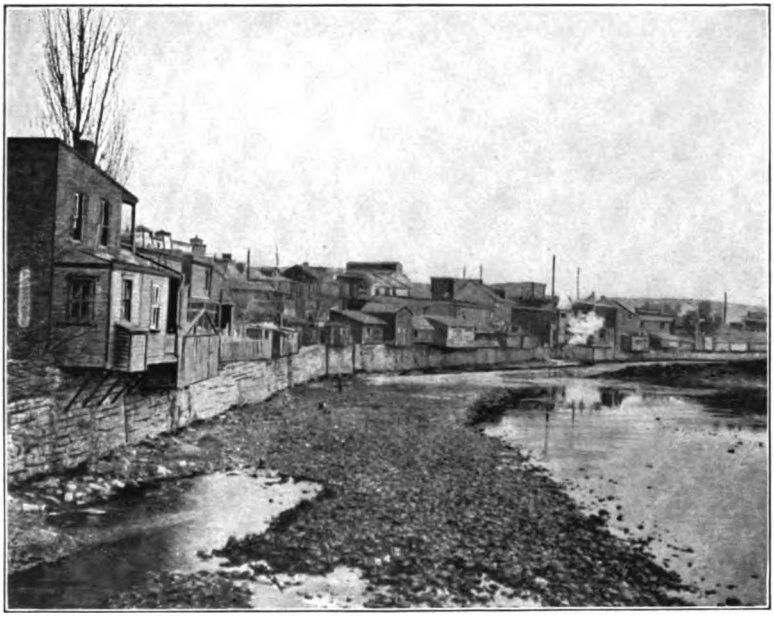
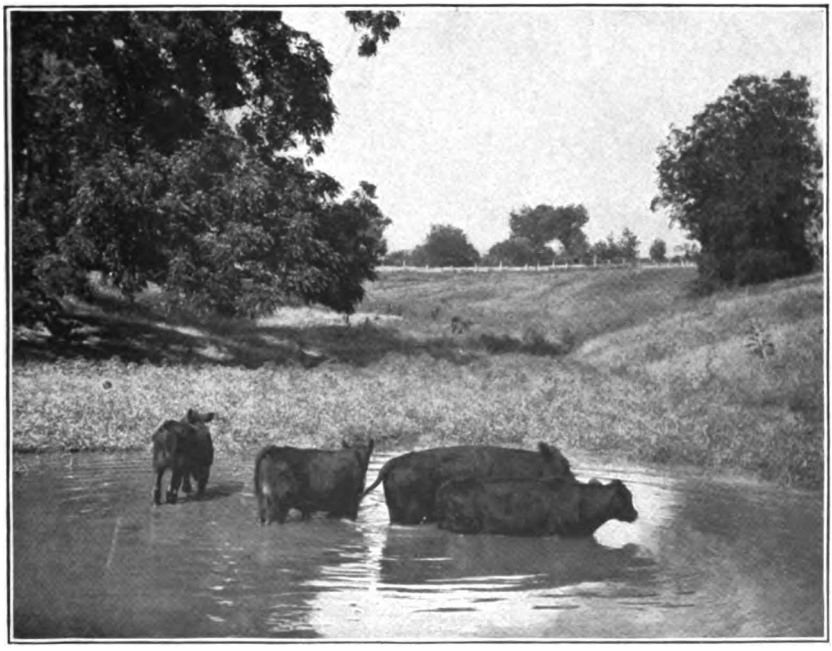


A. OUTHOUSES ALONG STREAM.



B. STOCK IN POND.

POLLUTION OF SURFACE WATERS.

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In the more hilly regions, such as those of New Hampshire and Vermont, especially where the farms lie in the valleys, the water from hillside springs can usually be piped with little difficulty to the house and barn, where it flows as a steady stream under the influence of gravity alone. A farm supplied from such a source is fortunate indeed.

Natural spring water is almost never dangerous to health, as the minerals it contains in solution are generally harmless, although a few waters act as a physic and others may contain sulphur gases in disagreeable amounts.

Wells.—Dug wells, because of the ease with which they may be constructed by the farmer himself when other work is not pressing, require little money outlay and are therefore very popular. As commonly sunk, however, they are the most dangerous of all sources of water, but with certain precautions, discussed elsewhere (p. 44), they may be made to yield satisfactory supplies.

Driven wells consist of iron pipes, equipped with point and strainer at the end, which are forced into the ground by blows on the top of the pipe. The joints are water-tight; hence the polluted waters near the surface can not possibly enter. Such wells are also very cheap and, in fact, possess advantages which make them most desirable. The fact that they can be put down only in soft materials, where no very hard beds or large bowlders are to be encountered, however, limits their use.

Drilled wells, usually from 2 to 12 inches in diameter, are sunk by machinery in materials too hard or too irregular to permit driving or in places where greater depths are required than can be reached by driving. In all soft materials which will not stand by themselves, or in material through which undesirable water might enter, an iron pipe, known as the "casing," is inserted, shutting off all impurities. Drilled wells are usually of considerable depth, some of them being carried to 2,000 feet or more if water is not found at higher levels. In granites and similar rocks most of the water is found within 300 feet of the surface, and if a supply is not obtained within that depth it is better to start a new well than to drill the old one deeper.

The chief disadvantage of such deep waters is the large amount of mineral matter which they may contain and which makes them unfit for boiler and manufacturing purposes. But to the farmer this feature is usually of no consequence. To him the principal question is the cost. The deeper wells are of course usually beyond his reach, but fortunately water can often be found relatively near the surface. Moreover, such waters, contrary to the common belief, usually contain less mineral matter than the deeper waters and can often be obtained in larger amounts.

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Cisterns.—Where a satisfactory supply can not be obtained from the ground, or where the ground water is hard and soft water is required for certain purposes, the rain falling on the roofs of the farm buildings is often utilized. It is conducted by pipes to shallow well-like excavations, which are commonly made at least approximately water-tight by linings of cement or other impervious material. When thus made they are generally safe to use, and the waters, being very soft, are highly prized for domestic purposes; but if cracks allow the outside waters to enter, cisterns are as liable to contamination as dug wells.

Summary.—Of the various sources of water supply the ground water is the most satisfactory for farm use, because it is least liable to pollution, and streams and ponds are the most unsatisfactory, because of the ease and frequency with which they are contaminated. Fortunately, however, the latter are very seldom used for drinking and domestic purposes, being utilized mainly for stock, on which the effect of moderate pollution is not apparent. The underground supplies, whether from wells or springs, although safe in many localities, are far from being universally so, the safety depending mainly on their location and on the nature of their protection. These are discussed in the following sections.

UNDERGROUND WATERS AND THEIR PROTECTION.

SPRINGS.

The term "spring" is properly applied to the water emerging from the ground at a single point or within a restricted area. The distinction between springs and general seepage, however, is not always very sharp, for there are all gradations between the concentrated outflows characterizing true springs and the diffused emergence of water over large areas or beneath the level of the water in streams.

Springs may be divided, according to their mode of origin, into gravity and artesian springs, and, according to the nature of the passages traversed by the water, into seepage, tubular, and fissure springs.

KINDS OF SPRINGS.

Gravity springs.—A gravity spring is one whose water is not confined between impervious beds but flows from loose materials or open passages under the action of gravity, just as a surface stream flows down its channel. The conditions are shown in figure 11.

Artesian springs.—An artesian spring is one whose waters are confined in impervious channels or between impervious beds and are under hydrostatic pressure because the water level at their source is higher than the point where they emerge. The waters of such a spring, if confined in a pipe instead of being allowed to flow out upon the ground, may rise considerably above the spring mouth.

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Seepage springs.—Seepage springs are springs in which the water seeps out of sand or gravel; they differ from general seepage only in being restricted to a small area. Such springs are usually marked by abundant vegetation at their points of emergence, and their waters are often colored or carry an oily scum due to the decomposition of vegetable matter or the presence of iron. The scum is frequently mistaken for petroleum. The waters of the seepage springs commonly come from no great distance beneath the surface and are not usually very cold.

Seepage springs may emerge along the top of an underlying impervious bed, but more commonly they occur where valleys are cut downward into the zone of saturation of a more or less uniform water-bearing deposit. Under favorable conditions the seepage from sands, as on Long Island, New York, gathers into channels and forms streams of considerable size, some of them flowing 5,000,000 gallons or more daily.

Seepage springs, as in the cases cited, are commonly of the gravity type, but where channels or fissures emerge beneath beds of sand or gravel seepages not infrequently result from true artesian springs.

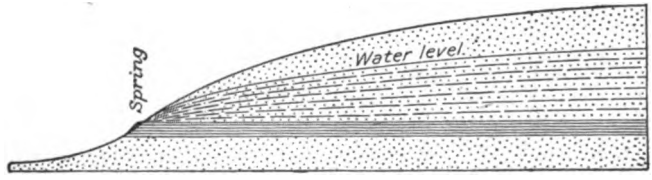

FIGURE 11.—Spring fed from unconfined waters in porous sands.

Tubular springs.—Tubular springs embrace a great variety of flows, including both those in the small more or less tubular passages in the drift and those occupying large solution channels or caverns in the soluble rocks.

The channels of springs in the drift are generally established along some more or less sandy or other porous layer, or perhaps along the path left by a decaying root. The motion at first appears to have been mainly that of seepage, but in many springs a passageway has been gradually opened, along which a definite stream finds its way. The waters reach the channels by percolation through the clays and sands and are usually free from pollution except when near cesspools or vaults sunk some distance into the ground.

In limestones and other soluble rocks the underground passages may reach many miles in length. Single passages, as in the Mammoth Cave of Kentucky, have been traversed for a distance of nearly 10 miles, and passages several times as long, though as yet undiscovered, probably exist. Some of these passages are many feet in diam-

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eter and are traversed by streams of considerable size, or even by rivers. The Silver Springs of Florida give rise to a river which is navigable from the ocean to its source in the springs, and springs of similar volume occur at other points in Florida and Arkansas and possibly elsewhere. The waters of such springs vary greatly in composition, although most of them are hard. In some springs the waters are exceedingly clear, the bottoms being distinctly visible at a depth of many feet, but in others the waters are muddy after severe storms. When clear it is probable that the waters feeding the underground stream reached it by percolation through the porous earth or rock, during which its impurities were largely removed. When muddy the waters in part appear to have penetrated downward through sinks or to have entered the rock directly as streams; in either case they are very liable to pollution by impurities washed in with the water.

Tubular springs are most commonly of the gravity type, the channels generally sloping from higher to lower levels. In both drift and limestone, however, there are numerous exceptional springs whose channels are at some points in their courses considerably lower than

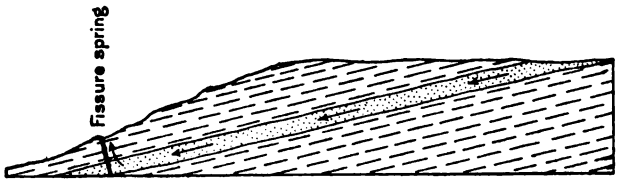

FIGURE 12.—Fissure spring.

their outlets. Under such conditions the water may be under considerable artesian pressure in the lower parts of its channel or even at its outlet.

Fissure springs.—The term fissure spring is here used rather comprehensively to include the springs issuing along bedding, joint, cleavage, or fault planes. (See fig. 12.) The distinguishing feature is a break in the rocks along which the waters can pass, it being immaterial whether any considerable open space exists. These springs differ from tubular springs in that they are as a class of deeper-seated origin, as is attested by their temperatures. The waters are almost never subjected to contamination, though in many springs they are highly mineralized. Springs of this class are often distributed along straight lines for considerable distances, their position being determined by lines of fracture or jointing.

SAFETY OF SPRINGS.

Springs from sands, sandstones, clays, shales, and slates are seldom polluted, except where contaminating matter penetrates through

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A. SPRING RECEIVING WASH FROM FERTILIZED LAND.

B. SPRING RECEIVING POLLUTION FROM STOCK AND SURFACE WASH.

POLLUTION OF SPRINGS.

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A. PROPERLY PROTECTED SPRING.

B. SPRING OPEN TO FALLING LEAVES, ETC.

POLLUTION OF SPRINGS.

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cracks or fissures, or through the material itself where the covering above the water is very thin. Usually such pollution is likely to occur only where houses, barns, sewers, or cesspools are located on higher ground near the spring, or more especially where cities or towns are so located. In limestones, on the contrary, sewage or other polluting matter frequently enters the underground channels through the sinks (Pl. VI, *A*) and may contaminate the underground water for long distances. Similarly in the tubular channels in the till, if material from a cesspool or other source of pollution finds access, the water may retain its contamination for a long period and a great distance.

PROTECTION OF SPRINGS.

Protection from stock.—One of the most common causes of contamination of springs in the farming districts arises from failure to fence the springs to prevent the access of stock. Plate VIII, *B*, shows a mineral spring in Georgia from which many people drink and from which the waters have at times been shipped, but about which stock are nevertheless allowed to roam freely, drinking from it at will and incidentally contaminating it in a variety of ways. It is needless to say that any spring used for drinking water should be carefully fenced at such a distance as to prevent any excrement from reaching it.

Protection from surface drainage.—The spring mentioned above is located only a few inches above the bottom of the stream channel shown on the right of the view. When the picture was taken no water was flowing in the channel, but at times of rain considerable volumes of water descend along the depression, covering the spring and washing into it all sorts of refuse from the hillsides above. Plate VIII, *A*, shows another spring, located in Missouri, receiving the drainage from a cornfield, together with such manure or other fertilizer as may be used in the cultivation of the crops. This water, which carries both sulphur and Epsom salts, is considered of medicinal value, but it is clear that, situated as it is, its safety is at least doubtful.

In general, it is not advisable to use springs for drinking water where their location normally exposes them to inflows of surface drainage. If other sources are not available, however, the spring should be carefully protected by impervious walls, which should be carried to sufficient height to keep out the surface water. An example of a spring protected from all such sources of pollution is afforded by the Bowden lithia spring, at Austell, Ga., shown in Plate IX, *A*.

Protection from wind blown and other refuse.—Another source of frequent and objectionable though not necessarily dangerous contamination is the leaves, paper, dust, and dirt blown into open springs by the wind. The spring shown in Plate IX, *B*, is a typical example of those surrounded by thick vegetation, and especially

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liable to contamination by leaves and forest litter. An example of danger from refuse of a more disgusting type is shown in Plate X, *A*. Located in the middle of a well-traveled street, only a few inches above a gutter filled with paper and refuse, a part of which is sure to enter whenever a heavy rain occurs; open to the rain which washes into it from the steps leading down to it such dirt from the street as is brought in by the feet of the users; subject to the dipping of all sorts of more or less dirty buckets and utensils; receiving the underground drainage and presumably more or less sewage from the buildings on the slopes above; and containing in its bottom several inches of decaying paper and other refuse, this spring is on the whole one of the worst and most dangerously located sources of drinking water in the United States.

Protection from subsurface drainage.—In farming districts pollution by subsurface drainage from buildings on the slopes above the springs is not very common, although many springs are located back of barns, below hogpens and outbuildings. The placing of buildings above springs intended for use should always be avoided, even if

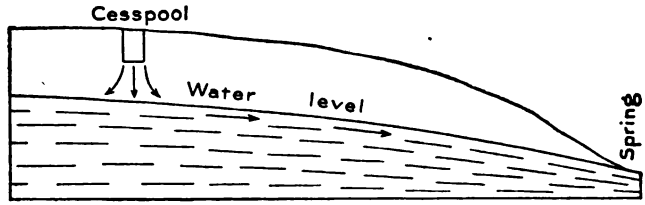

FIGURE 13.—Diagram showing manner in which springs may be polluted by subsurface drainage.

the spring is several hundred feet away from the proposed site. (See fig. 13.)

Protection of sink holes.—It has already been pointed out that much of the water in limestones, the springs of which are frequently used for drinking and domestic purposes, enters the rock through open sink holes, into which in some places manure and other refuse has been dumped or sewage drained. Plate VI, *A*, shows a small but continuous stream of sewage from a large college building discharging into a sink from which it finds its way to the underground water channels. Such practices are very dangerous. Cases of typhoid fever have resulted from drinking water from springs or wells which have become polluted by such matter entering the sinks; and even where specific pollution is absent, undesirable slimes and rubbish often render the water highly objectionable. Instead of discharging refuse or sewage into sinks, every care should be taken to protect them against its access.

Use of lead pipes.—Spring water should always be conveyed by iron pipes, as lead, which was formerly much used, is more or less

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A. SPRING IN CENTER OF CITY STREET.

B. DAIRY SPRING FROM POLLUTED UNDERGROUND STREAM.

POLLUTION OF SPRINGS.

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readily dissolved by soft waters. Thousands of cases of lead poisoning resulted from such use in Europe and America before the cost of lead pipes became so high that they were largely abandoned.

Where the water flows continually there is little danger from lead pipes, but if the flow is shut off when not in use, enough water should be drawn off each time to remove entirely that which has been standing in the pipes before taking any for domestic purposes or for the use of stock.

Tests for pollution.—There is no infallible chemical test for the detection of pollution in small amounts. If a chemist is thoroughly familiar with the normal character of water in the immediate vicinity, he may be able to detect contamination by means of chemical examination; but waters contain so many harmless substances dissolved from the earth that the determinations by a chemist are often inconclusive. Careful observation of the spring itself and a common-sense inspection of its surroundings are usually of more value than an analysis. The spring should be protected from pollution, especially from surface drainage from houses, barns, hogpens, and other outhouses that are situated on the slopes above it within a distance of several hundred feet. When the absence of such local sources of pollution is established, the water should be carefully watched, especially in limestone regions, for muddiness or floating matter rising with the water after severe rains. Such phenomena are evidence of connection with sink holes and indicate that the water is to be looked upon with grave suspicion if opportunity exists anywhere within miles for the entrance of polluting matter through sinks or otherwise. Plate X, *B*, shows a spring in Greene County, Mo., used for dairy purposes. The spring is remote from buildings and the water is clear, cold, and sparkling, but is, nevertheless, more or less polluted, owing to the fact that the underground stream feeding the spring appears at the surface at a number of points above it, crossing one or more highways and receiving the drainage from them and from a cemetery.

WELLS.

GENERAL DISCUSSION.

Because of their cheapness, convenience, and fancied safety, wells are by far the most popular source of domestic supplies in all regions in which water is found at reasonable depth. If properly located and constructed they afford an ideal source of supply fully justifying their popularity. But if they are carelessly finished or improperly located they are much more liable to pollution than is commonly supposed, and it is with the view of pointing out some of the precautions that should be taken for their protection, as well as of

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presenting information concerning desirable types, location, and construction, that the following discussion is presented.

TYPES OF WELLS.

Although no two wells are exactly alike in all particulars, there are, in reality, only a few distinct forms, the others being simply modifications or combinations of these. (See Pl. XI–XV; figs. 14–16.) The kind of well to be sunk at a particular locality depends mainly on the nature of the material to be encountered, one form being particularly adapted to a certain material, such as sand, while an entirely different form is demanded if rock is to be penetrated. The following tables show clearly and concisely the characteristics and methods of sinking the more common types and point out the conditions to which they are best adapted:

Types of wells and conditions to which they are adapted.

Type of well.	Description.	Conditions to which well is best adapted.
Dug	Generally circular excavations, 3 to 6 feet in diameter, dug or blasted by hand and curbed with wood or with stones or bricks laid without cement.	Adapted to localities where the water is near the surface, especially where it occurs as small seeps in clayey materials and requires extensive storage space for its conservation. Should not be near sources of pollution.
Bored	Bored with various types of augers from 2 inches to 3 feet in diameter, rotated and lifted (together with the earth) by hand or horsepower. Curbed with wood, cement, or tile sections, with open or cemented joints, and more rarely with iron tubing.	Adapted to localities where the water is at slight or medium depths and to materials similar to those in which open wells are sunk.
Punched	Small holes, usually under 6 inches in diameter, sunk by hand or horsepower, by dropping a steel cylinder slit at the side so as to hold and lift material by its spring. Clay is added to incoherent materials like sand to bind them together so that they can be lifted.	Adapted to clayey materials in which water occurs as seeps within 50 feet of surface, but not at much greater depths.
Driven	Small iron tubes, usually 1¼ to 4 inches in diameter and provided with point and screen, driven downward by hand or by simple hand or horsepower apparatus.	Adapted to soft and fine materials, especially to sands and similar porous materials carrying considerable water at relatively slight depths. Particularly desirable where upper soil carries polluting matter.
California or stovepipe	Overlapping sheet-steel casings, 4 inches or more in diameter, forced downwards by hydraulic jacks and finally perforated by a special apparatus at water strata. Drillings are removed by a long sand-bucket with valve.	Adapted to soft materials extending to considerable depths and having several water strata capable of utilization.
Standard drilled	Sunk by percussion of heavy drill, 1½ to 12 inches or more in diameter, lifted and dropped from portable rig or derrick by horse or steam power. Cased with iron pipe in soft materials; usually not cased in rock. Drillings removed by long bucket with valve in bottom.	Can be used to advantage in all but the softest materials, but is particularly adapted to rock work, especially at great depths, being cheaper and quicker than other methods of drilling in rock.
Diamond-drill hole	Sunk by rotating hollow bit, usually 1¼ to 4 inches in diameter, with rim fitted with black diamonds. Penetrates by abrasion due to rotation. Drillings removed by water forced down drill and up along outside of rods.	Not adapted to water wells because of great cost. Used where cores of materials penetrated are required, or where hole is sunk at an angle with the vertical.

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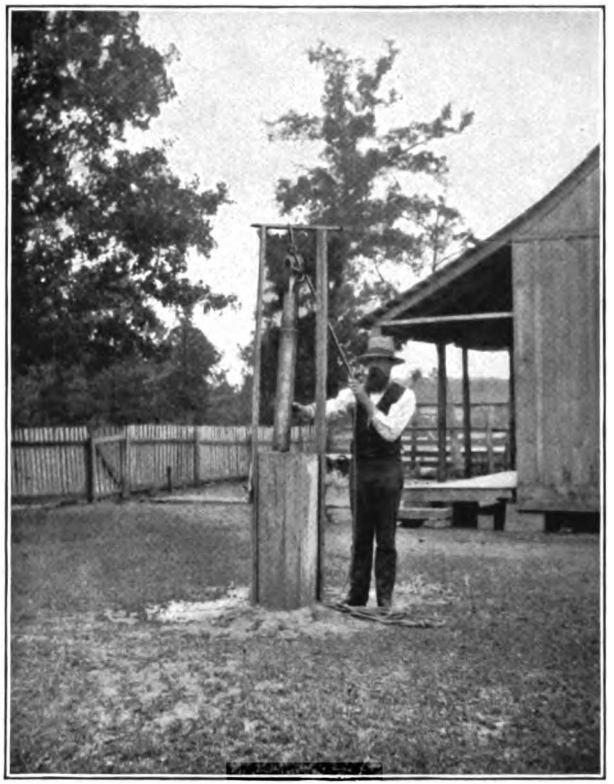
A. OPEN DUG WELL.



B. BORED WELL.

TYPES OF WELLS.

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A. THE JET OUTFIT.

B. THE DRIVEN WELL.

METHODS OF SINKING WELLS.

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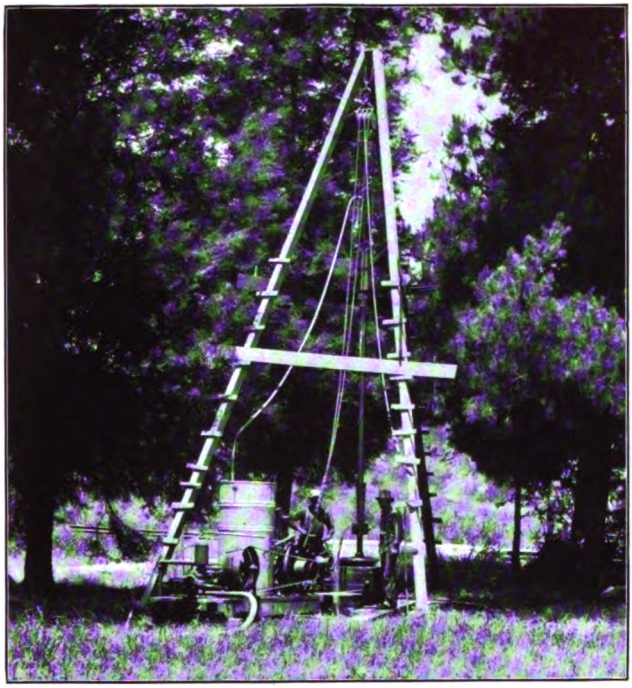

A. STANDARD PORTABLE RIG.

B. ROTARY APPARATUS.

METHODS OF SINKING WELLS.

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A. PITCHER PUMP.

B. DEEP WELL PUMP.

METHODS OF RAISING WATER.

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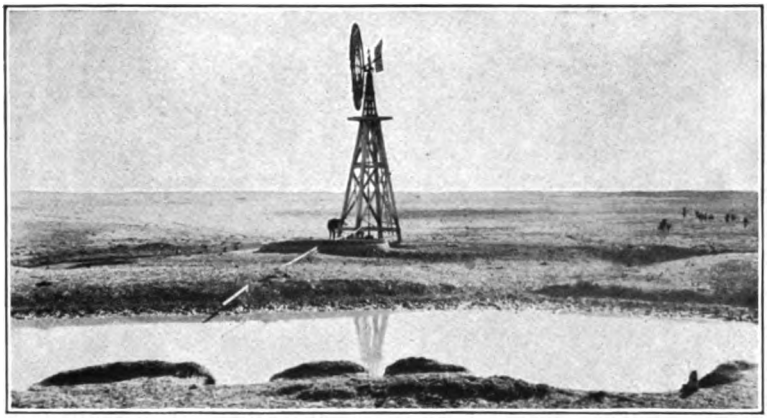
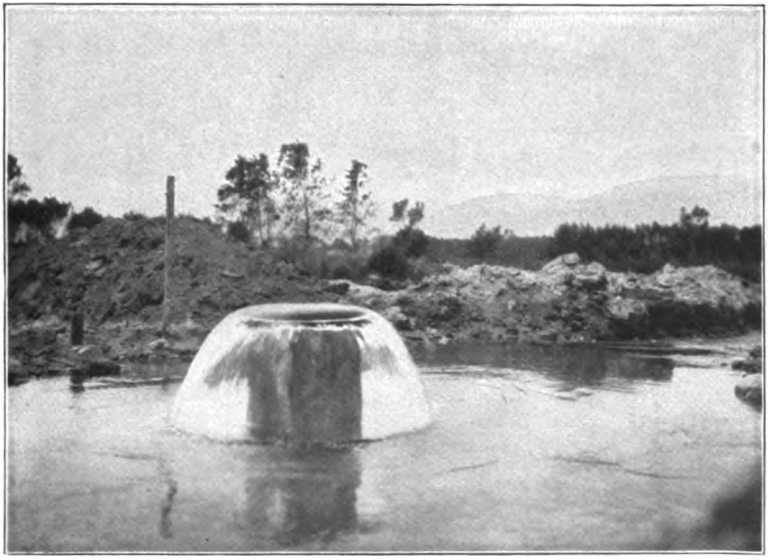


A. WINDMILL.



B. NATURAL FLOW.

METHODS OF RAISING WATER.

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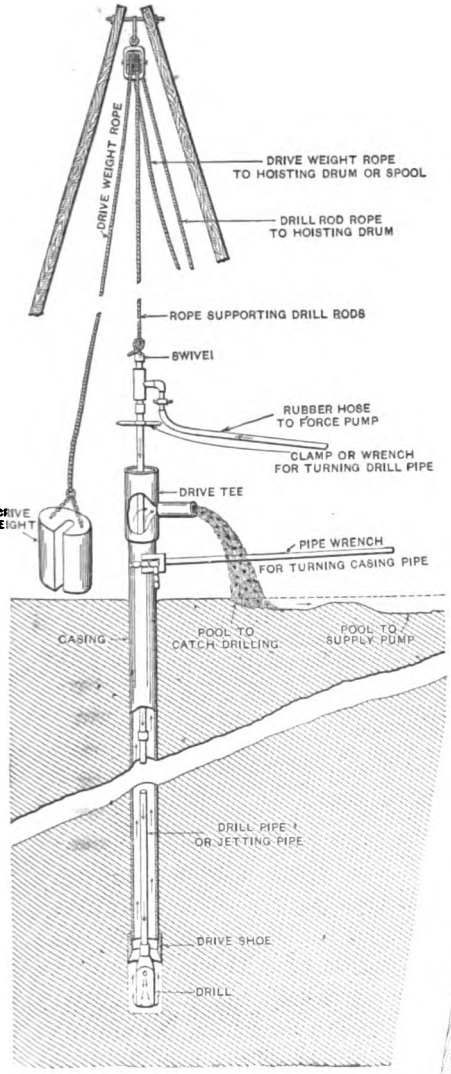

FIGURE 15.—Outfit for sinking wells by jet process.

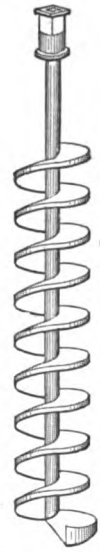

FIGURE 14.—Common form of well auger.

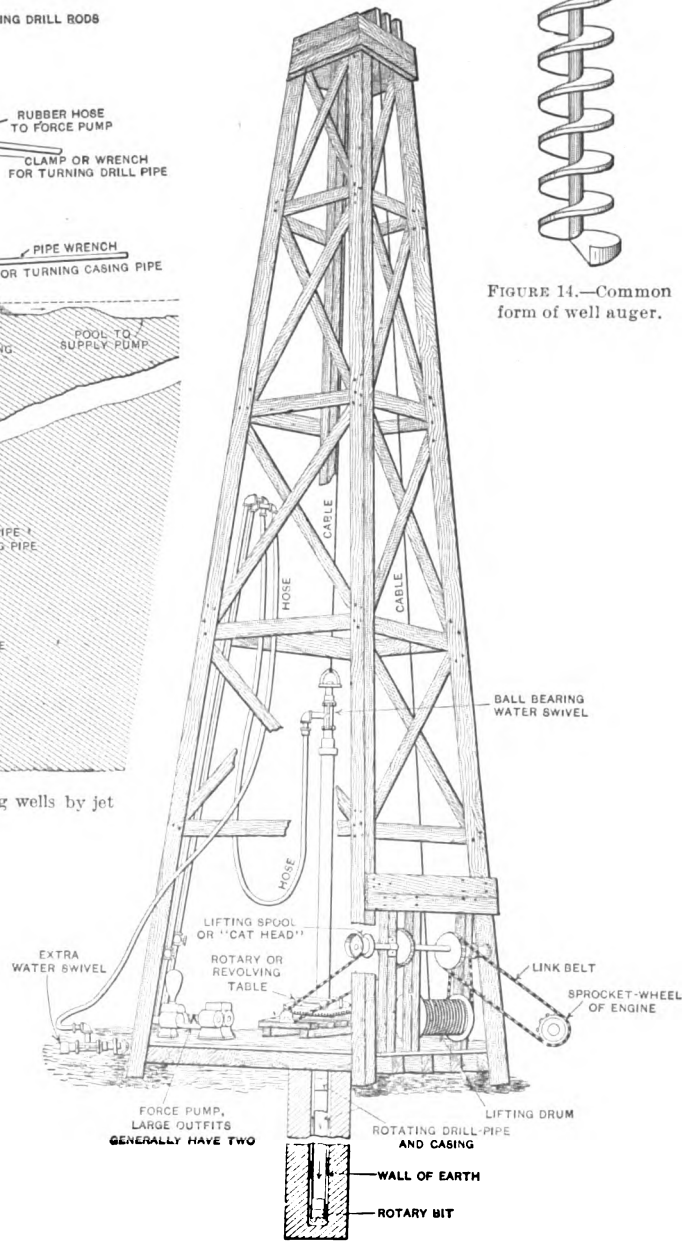

FIGURE 16.—Outfit for sinking wells by rotary process.

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Types of wells and conditions to which they are adapted—Continued.

Type of well.	Description.	Conditions to which well is best adapted.
Wells sunk by calyx and steel-shot methods.	Sunk by rotation of notched steel shoe, or by chilled steel shot used in connection with a rotating plain shoe of soft iron. Rods by which power is transmitted are hollow and permit the dropping of the shot and the entrance of water, which brings up the cuttings as with the diamond drill.	Adapted to vertical work in hard rocks where cores are required. Cheaper but slower than diamond-drill method, and more expensive than standard drilled holes. Is successfully used as an adjunct to hydraulic rotary process.
Wells sunk by jet process.	Sunk by forcing water down small iron "jet pipe" inside of casing, the water rising between the two with the drillings. Casing sinks by own weight or is forced down by jacks or otherwise. Diameter usually 2 to 4 inches.	Adapted to soft materials capable of being readily broken up by the water jet, especially to sands, etc., carrying considerable water at relatively slight depths. This method is an improvement over driven wells, which are adapted to same conditions, because it affords samples of materials penetrated. Quick and fairly cheap and especially useful in sinking large numbers of test wells in adjacent localities.
Wells sunk by hydraulic process.	Sunk by lifting and dropping drill in hole full of water. Penetrates by percussion. Water and cuttings are forced into hollow rod on down stroke, being retained by valve. Diameter similar to standard drilled wells.	Adapted to clays and other unconsolidated deposits and to soft rocks where depths are moderate and the use of a heavy drill is not required.
Wells sunk by hydraulic rotary process.	Sunk by rotating steel shoe, as in calyx method, but with the difference that whole pipe is turned and water is forced down pipe and up outside instead of through rods. Steel shot also sometimes used.	Adapted to rapid work at considerable depths in materials prevailingly soft, but having occasional hard layers.

TYPES OF CURBS AND CASINGS.

Just as there are various types of wells, so are there various methods of curbing and casing (or lining) the well, each method being likewise particularly adapted to a special type of well or to a certain definite kind of material. In some types of wells—for example, in dug, bored, and punched wells—several kinds of curbing or casing may be used, and the selection should be governed by the sanitary protection or resistance to the entrance of pollution which the casing affords. On no other single thing does the safety of the well depend to so great an extent as on the nature of the curbing or casing employed. The more common types of curbings and casings, their advantages and disadvantages, and the conditions to which they are best adapted are shown in the following tables:

Types of well curbs and casings.

Type.	Nature.	Conditions to which best adapted.
Rock	Broken or dressed rock laid without cement, usually in circle 3 to 6 feet in diameter.	Adapted to shallow dug wells, in materials carrying water mainly as small seeps, where there is no near-by source of pollution.
Brick	Porous brick laid without cement, usually in circles 3 to 6 feet in diameter.	Same as rock curbs.
Cement-lined rock or brick.	Brick or stone as above, but laid in and lined with cement.	Adapted to shallow-dug wells in materials carrying enough water to permit an adequate supply to enter at the bottom. Can be used in polluted soils if the contamination is superficial and does not reach to the bottom.

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Types of well curbs and casings—Continued.

Tppe.	Nature.	Conditions to which best adapted.
Wood	Square wooden boxes in wells over 3 feet in diameter; cylindrical curbs of narrow staves in wells under 3 feet in diameter.	Can be placed in any shallow well, but are never safe and should never be used.
Tiles	Glazed sewer tile, cement tiles, and porous terra cotta tiles, laid without cement.	Adapted to conditions similar to those of rock and brick curb.
Do	Glazed sewer tile and cement tile with cemented joints.	Same as cement-lined stone or brick curbs, except that it is more applicable to wells of small diameter.
Heavy iron casings	Iron pipes, 1 to 4 inches in diameter, with tight joints.	Adapted to wells of all depths in which water is obtained from a stratum below the casing, or from strata between cased sections. Not adapted to strongly corrosive waters.
Sheet-iron casings	Iron pipes 4 to 16 inches in diameter, with snug joints.	Adapted to wells of all depths, in loose material, in which it is desired to procure water from a number of strata.

Summary of advantages and disadvantages of different types of well curbs and casings.

Type of curbing.	Advantages.	Disadvantages.
Rock	Allows all water to enter, thus utilizing all seeps. Material often costs little or nothing. As a rule requires little money outlay for labor.	Polluting matter enters readily and well is never safe if near sources of contamination. Affords no filtration and permits dirt and soil to enter. Permits entrance of mice and other small animals at top.
Brick	Where uncemented it allows all water to enter, utilizing all seeps. Filters out most of sediment. Does not allow small animals to enter. Involves little money outlay for labor.	Polluting matter enters readily, and well is never safe when near sources of contamination. Material costs considerable.
Cement-lined rock or brick.	Safe from pollution (except that entering at bottom) as long as walls are not cracked. Prevents entrance of sediments. Prevents entrance of animals. Does not impart taste to water.	Utilizes water from bot om only. Is unsafe if so shallow that polluting matter can reach its bottom. Costs considerably more than uncemented wells. May require skilled labor.
Wood	Cheap in many localities. Can be used in wells of very small diameter. Does not taste of iron.	Swells tight in wet ground, the water either entering at bottom or (after sudden rises) through shrunk portion at top. Pollution enters readily. Animals gnaw through. Wood rots, giving taste to water and favoring development of bacteria. Expensive in some localities.
Glazed and cemented tiles with uncemented joints.	Allows all water to enter, utilizing all seeps. Does not give taste to water. Does not require skilled labor.	Polluting matter enters readily and well is never safe if near source of contamination. Soil may wash in through joints. Requires some outlay for material.
Glazed and cement tiles with cemented joints.	Safe from pollution (except that entering at bottom) as long as joints are tight. Does not require expensive labor.	Can be used only in soft materials containing considerable water.
Iron casings	Adapted both to rock and to unconsolidated materials. Safe from pollution except that entering at bottom.	The cost in large deep wells is considerble. Practically limited to wells under 14 inches in diameter. Is subject to deterioration by corrosion and incrustation in some places. Utilizes but one water stratum (except where perforated).

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FACTORS GOVERNING SELECTION OF TYPE OF WELL.

The type of well is the first and perhaps the most important point to be decided. Of the many kinds in use, including the dug, bored, and driven types and wells sunk by the jet process or drilled by rotary or percussion rigs, each possesses, on the one hand, one or more points especially qualifying it for use under one or more of the many varying conditions encountered in drilling, and on the other hand, some disadvantage which may disqualify it for use under certain other conditions. The chief factors which govern the selection of type are, usually, the amount of water needed, the character of the materials to be penetrated, the depth to which the well must be sunk, the cost of sinking the well, and the safety of the resulting supply. These factors are considered in detail in the following paragraphs.

YIELD OF WELLS OF VARIOUS TYPES.

If an adequate supply of ground water is available, the yield of a well will depend on the character of the water-bearing material, the facility of entrance of water, the size or storage capacity of the well, and the nature of the pumps.

Character of the material.—The character of the water-bearing material is of the greatest importance in determining the yield of a well, as it is on the structure and texture of the water-bearing beds, that the amount of water which they will give up depends. A close-textured clay, for instance, may hold as high as 45 per cent and a chalk as high as 53 per cent of its volume, while an open-textured sand may hold as little as 26 per cent of its volume. Notwithstanding this a sand will ordinarily yield large supplies, whereas a chalk and especially a clay will yield little or no water. In quicksands water is usually present in large amounts, but owing to the absence of good foundations for the curbing and the ready flow of the fine sand through the minutest crevices, ordinary dug wells in such material are generally out of the question and even driven wells equipped with the ordinary strainers usually soon become clogged. Driven or drilled wells equipped with special screens and sunk by experts familiar with the various methods of handling quicksand are usually the only types entirely successful in such material.

Structures, such as solution passages, bedding planes, or joints, play an important part in determining the yield of a well. A solution passage in limestone may afford inexhaustible supplies where the mass of the rock is practically destitute of water. In other rocks the bedding planes and joints may afford excellent supplies where no water is found in the rock itself. The amount of water present in the pores of different rocks is indicated by the following average porosities: Sandstones 15 per cent, shales 4 per cent, limestones 5 per cent, crys-

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talline rocks 2 per cent. The water present in the larger openings mentioned, though small in amount in comparison to that held in the pores, is yielded much more rapidly and, except in sandstones and similar porous rocks, usually affords the principal source of supply.

Facility of entrance.—The facility with which water enters the well depends in part on the rock features enumerated and in part on the nature of the well. In loose materials water accumulates most easily in stone-curbed and similar types of dug wells and only less so in tightly curbed dug wells with open bottoms. Where the water bed is a strong one and the materials are sufficiently consolidated to prevent them from entering the well the water will freely enter an iron casing open at the bottom. In weak water beds in soft materials, and in quicksands, either perforated casings or casings equipped with long screens are necessary to permit the entrance of the required amount of water. In many of the harder rocks the walls will stand without caving and casings are therefore unneccessary, the water entering at any point without hindrance.

Storage capacity of wells.—Where strong water beds exist storage is unnecessary, the water entering from the rock as fast as the pumps demand. Where the supply is derived from weaker beds, especially those having only small seeps, storage is a significant factor and the type and size of the well are of great importance. The volume of tubular wells of equal depth varies with the square of their diameters, hence a 6-inch well will hold nine times as much water as a 2-inch well of the same depth, and a 3-foot well thirty-six times as much as a 6-inch well. Dug wells are therefore of advantage in clays and similar materials where the water enters more slowly than it can be lifted by the pumps, for they permit accumulations that may tide over periods in which the amount used is greater than the supply. For the deeper rock waters dug wells are impracticable and small-bore drilled wells must be used even where the supplies are slight. To get the best results the wells are generally made as large as can be afforded and sunk considerably below the point of entrance of the water, to afford the necessary storage.

DEPTH OF THE WATER.

The depth of the water is a factor of importance in the determination of the type of well to be sunk. A dug well, for instance, is suitable only when the water is within 30 or 40 feet of the surface, although many deeper dug wells exist. A punched well is commonly limited to depths of 50 feet, and a bored well is with difficulty carried to depths greater then 100 feet. Driven wells are most suitable at depths of less than 150 feet, although they are sometimes successfully extended to depths of 250 to 300 feet, or even to 400 or 500 feet or

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more, where the conditions are favorable. Jet wells are usually sunk only where it is not necessary to go much more than 100 feet from the surface. Wells of the California type are frequently extended to depths of 1,000, and occasionally to depths of 2,000 feet. Hydraulic rotary wells are successful to depths of 1,000 or 2,000 feet in the proper rocks. The percussion or churn drill may be used for all depths down to 5,000 feet, or deeper if special outfits are provided. Diamond drills have been successfully used to depths of 6,000 feet.

RELATIVE COST OF WELLS OF DIFFERENT TYPES.

So many items, such as accessibility to fuel, cost of labor, trade combinations, knowledge of water conditions, relative availability of different drilling outfits, and local practice, enter into the cost of a well that few definite statements can be made. Instances are not uncommon where wells of certain types have been put down for one-tenth the price demanded for wells of the same type in other regions where conditions are essentially similar. In general, however, if only actual outlay of money is considered the dug well is the cheapest, for it may be constructed by the owner himself at times when he has nothing else to do. Bored and driven wells do not require expensive rigs and are often cheaper than dug wells when paid labor is employed in their construction. California wells for deep bores in soft materials are moderately cheap where the proper outfits are available, but unfortunately their use is as yet confined mainly to a single region. The jet process is adapted to the sinking of a large number of adjacent wells in soft materials, especially sand, and is occasionally successful for single wells, although in most places driven wells can be put down at less cost. The hydraulic and rotary processes may be cheaper than straight drilling where there are numerous alternations of hard and soft material. Of the processes in use for drilling in rock the standard rig (percussion drill) is the cheapest, the calyx and diamond systems being generally used only when cores of the rocks penetrated are desired. A more detailed comparison of the methods is given in the subjoined table. Although the relative costs indicated are fairly constant over the country as a whole, the cost of any method in a particular locality may be entirely abnormal, owing to the lack of drilling outfits capable of doing the work or to the existence of peculiar conditions rendering its operation difficult.

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Cost of wells.

[By O. E. Meinzer.]

Formation.	Diameter in inches.	Locality.	Explanations.	Cost per foot.
Limestone	6	Illinois, Iowa, Minnesota, Wisconsin.	No casing required	50 cents to $1.
Glacial drift and Cretaceous shale.	2	Iowa and Minnesota.	Heavy iron casing furnished; water guaranteed.	55 cents to $0.75+.
Do	4	do	do	$1±.
Glacial drift	4 to 6	Illinois	Light casing furnished	50 cents or more.
Do	Bored, 6 to 36	Minnesota and Iowa.	Casing not furnished; planks or tiles are used. These are expensive per foot, but the wells are not as deep as the drilled wells.	50 cents to $1+, increasing with depth.
Glacial drift and Cretaceous shale (mostly soft shale).	1¼ at bottom	South Dakota artesian basin.	Casing furnished; flow of clear water guaranteed.	$350 to $500 for a well 900 to 1,000 feet deep.
Clay, free from bowlders.	1¼	Utah	Casing not furnished	20 cents.
Clay, sand, and gravel.	Dug, 3 to 4 feet	do	Not cased	$1.50 to $2, increasing with depth.
Quartzite	6	Minnesota	No casing required; yield of 3 barrels an hour guaranteed.	$3 to $4.
Alluvium	4 to 12	California	Casing not furnished. Stovepipe casing costs from 32 cents a foot for 4-inch 16-gage pipe to $1.40 a foot for 12-inch 10-gage pipe.	30 to 65 cents a foot for 4 to 10 inch wells, for first 100 feet, with additional charge of 25 to 35 cents a foot for each additional 50 feet in depth.

SAFETY OF WELLS.

The safety of a well depends on the purity of the water at its source and on its protection against the entrance of contaminated waters and polluting solids. The type of well does not affect the purity of the original source; but if the water supply is primarily pure, its maintenance in that condition depends largely on construction that prevents contamination.

Polluting matter finds entrance to wells in a variety of ways. In dug wells it enters through the crevices in the stone, brick, or wood curbing, or possibly through the brick itself; in bored wells it enters through the uncemented joints of the tiling or through cracks between the staves of tubular wooden curbing; and in drilled and driven wells through leaky joints or holes eaten in the iron casing by corrosive waters. By cementing the interior surfaces of stone or brick curbed wells, by replacing wood by cement or other impervious curbs, and by substituting new pipes for leaky iron casings the entrance of polluting matter through the walls can be prevented. Little or nothing enters the small tubular wells from the top and they may, therefore, be regarded as free from danger of pollution from this point. The larger open wells should be protected by a water-tight iron or cement cover standing somewhat above the level of the surrounding ground and tightly joined to the curb proper. The sloping of the earth away from the well serves to turn rainwater or pump

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drippings away from it, so that little will penetrate, even if the curb becomes cracked by frost.

A particularly dangerous type of well—the more so because of the fancied security of the owners—is the combination dug and drilled type. Because of a slight saving of expense, drilled wells are frequently sunk in old dug wells, the casing commonly beginning at the bottom of the old well. Although the water encountered by the deep well may be perfectly pure, it is liable to be contaminated, especially after rains, by the entrance of seepage waters into the open well and thence into the drilled well. The remedies are obvious; either the casing should be carried to the surface of the outside ground, or at least above the highest level ever reached by the water, or the open well should be converted into a water-tight cistern by the application of a thick coat of cement over both sides and bottom.

SUMMARY.

The factors determining the desirability of wells of different types are concisely summarized in the following table, in which the first column shows the chief advantages of each type, while the second column shows the offsetting disadvantages.

Summary of advantages and disadvantages of different types of wells.

Advantages.	Disadvantages.
Dug wells.	
Ease of construction; can be located, sunk, and cased by owner.	Limitation to soft materials; liability to caving while being dug.
Only hand power required.	
No outfit required.	
No expensive materials required for curbing.	
Cheapness in soft material.	Costliness in hard rock.
	Wood curbing often used affords favorable conditions for the development of bacteria.
	Slight depth to which it can be sunk.
Ease of entrance of water.	Ease of entrance of polluting matter through and over top of curb.
Utilization of all water strata.	Water, not being replenished, is often stagnant.
Utilization of small seeps.	Fails frequently in time of drought.
Quick response to rainfall.	Must usually be at distance from house and from barns, privies, and cesspools to insure safety.
Large storage capacity.	Necessity for frequent cleaning; danger from gas while cleaning.
Accessibility for cleaning.	Short life when curbed with wood.
	Ease of entrance of animals and refuse through open top.
Bored wells (Iowa type, 1 to 3 feet in diameter, pervious curbing).	
Ease of construction; only hand or horse power required.	Slowness of method as compared with driving.
No expensive materials required for curbing.	Special outfit required for all but small shallow holes.
Cheapness.	Limited to soft materials.
Utilization of all water strata where curbed with uncemented tile.	Ease of entrance of polluting matter through curb and over top.
Utilization of small seeps.	Limitation of points of entrance of water to top and bottom with many wooden curbs.
	Wood curbs favor development of bacteria.
Quick response to rainfall	Water, not being replenished, is often stagnant in larger bores.
Considerable storage capacity.	Failures frequent in droughts.
Accessibility of larger types for cleaning.	Necessity of location at distance from house to insure safety.
	Necessity of frequent cleaning; danger from gas while cleaning in the larger types.
	Limitation of practicable depth of large bores.
	Limitation of size.
	Short life when curbed with wood.

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Summary of advantages and disadvantages of different types of wells—Continued.

Bored wells (Arkansas type, 2 to 12 inches in diameter, tight casings).

Advantages.	Disadvantages.
Ease of construction; only hand or horse power usually required; skilled labor not essential in shallower holes. Cheapness for moderate depth. Deeper wells little affected by drought. Pollution shut out if properly cased. Gives good records of materials penetrated and water beds encountered.	Limitation to soft materials. Not adapted to very deep wells. Utilizes only one stratum in most places. Other disadvantages similar to those of drilled wells.

Punched wells.

When provided with pervious curbings the advantages are similar to those of open and Iowa type bored wells; when provided with tight casings the advantages are similar to those of the Arkansas type bored wells.	Similar to those of open wells and the larger type of bored wells. Difficulty of operation; liability of crooked holes. Usual limitation to depths under 50 feet. Limitation to soft yet stiff materials, which are generally of local distribution.

Driven wells.

Ease of construction; often sunk in a few hours; only hand or horse power usually required.	Limitation to soft materials.
Outfit is inexpensive, can be quickly put up, and does not require skilled labor.	Utilization of a single water stratum.
Tubing is readily obtainable and inexpensive. Cheapness.	Usual limitation to moderate depths. Restriction to open porous water beds due to absence of storage facilities.
Safety; can be located near sources of pollution if sunk through impervious bed preventing access of contaminating matter to water bed; nothing can enter at top.	Slow response to rainfall as compared to many dug wells. Corrosion of pipes or well points. Incrustation of pipes and well points.
Permanency of supply as compared with dug wells.	Entrance of quicksand through well points.
Cleaning seldom necessary as compared to open wells.	Taste of water due to solution of the iron under certain conditions. Difficulty of cleaning in case of clogging. Short life as compared to some dug wells. Absence of information as to minor water beds or materials penetrated.

Stovepipe or California wells.

Utilization of all horizons of water. Cheapness of casings as compared with large-sized driven or drilled wells. Shortness of sections, permitting use of steady pressure by hydraulic jacks.	Limitation to soft materials. Lack of strength of casing; distortion by lateral pressure; pulled with difficulty if distorted. Thinness of casing and shortness of life where waters are corrosive. Expensive; requires elaborate outfit available in only a few sections of country, skilled labor, etc.
Adaptability to conditions where driving is impossible. Flush outer casings and absence of screw joints. Ready adjustment to strains. Avoidance of clogging of perforations. Exclusion of sources of pollution. Affords fair records of materials and water beds encountered.	Cleaned with difficulty. Slight storage capacity. Taste of water due to solution of iron by corrosive waters. Short life under some conditions.

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Summary of advantages and disadvantages of different types of wells—Continued.

Standard drilled wells.

Advantages.	Disadvantages.
Adapted to all rocks.	Expensive; requires elaborate outfit, skilled labor, steam power with the attendant charges, and costly casing and pumps in deeper wells.
No ordinary limitation as to depth.	Many difficulties in drilling; frequent losses of tools.
Can be readily deepened.	Cleaned with difficulty.
Little affected by droughts.	
Can utilize all water strata where there is no great difference in head if casing is perforated, but this is rarely done.	Slow response to rainfall; slight storage capacity.
Pollution is completely shut out if properly cased.	Corrosion of pipes and screens.
Can be located anywhere.	Incrustation of pipes and screens.
Gives fair records of materials and water beds encountered.	Entrance of sand through screens or clogging of screens.
	Taste of water due to solution of iron under certain conditions.

Diamond-drill holes.

Gives complete core of rocks penetrated.	Adapted only to hard rocks.
Can be drilled at any angle.	Requires costly outfit and materials, skilled labor, steam power, etc.
Other advantages similar to those of other drilled wells.	Cost greater than drilled wells.
	Other disadvantages similar to those of drilled wells.

Wells sunk by calyx and steel-shot method.

Outfit and cost of sinking less than in diamond-drill holes.	Both outfit and cost of operation more than in drilled wells.
	Only vertical wells can be drilled.
Readily used in connection with hydraulic-rotary rig when hard rocks are encountered.	Slower than diamond drilling.
Other advantages similar to those of drilled wells.	Other disadvantages similar to those of drilled wells.

Wells sunk by jet process.

Rapid in soft materials; operates continuously.	Limited to soft materials.
Cheap compared with hydraulic, hydraulic rotary, and drilling methods.	Requires more apparatus than driven wells; requires skilled labor.
Supplies inexpensive and readily obtainable.	Requires previous supply of water.
Adapted to incoherent materials, such as sand, not capable of standing alone.	Small water seams not readily recognized.
Affords fair records and samples of materials penetrated.	Draws from single water bed.
Other advantages similar to those of driven wells.	Requires strong water beds due to absence of storage facilities; seeps can not be utilized.
	No storage capacity.
	Usually limited to small diameters.
	Satisfactory only in wells of moderate depth.
	Slow response to rainfall as compared to shallow-dug wells.
	Corrosion and incrustation of pipes.
	Taste of water due to solution of iron by corrosive waters.
	Difficulty of cleaning.

Wells sunk by hydraulic process.

Rapid in soft materials.	Usually limited to relatively small diameters.
Can be used where soft and hard beds alternate, but works best in uniform materials. Penetrates hard beds by fall of drill.	Requires previous supply of water for drilling process.
Operation nearly continuous.	
Affords good records.	Other disadvantages similar to those of drilled wells.
Other advantages similar to those of drilled wells.	

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Summary of advantages and disadvantages of different types of wells—Continued.

Wells sunk by hydraulic rotary process.

Advantages.	Disadvantages.
Very rapid in soft materials.	Satisfactory only where the materials are prevailingly soft.
Applicable to alternations of soft and hard material.	Small water seams not readily recognized; shut off by puddling by thick sludge.
Operations are relatively continuous; little lost time.	Requires previous supply of water for process of sinking well.
Can penetrate hard beds by use of calyx appliance and chilled-steel shot.	Affords unsatisfactory records.
	Possible for polluting matter to penetrate by passage through loosened zone and casing.
Other advantages similar to those of drilled wells.	Other disadvantages similar to those of drilled wells.

OPEN OR DUG WELLS.

LOCATION.

The chief considerations in the location of open wells and wells in which pervious casings are used, in the order of importance usually ascribed to them by the owners, are: Cost, accessibility, convenience, and safety. The requirements, unfortunately, often conflict. Most houses and barns are located on elevations for the sake of good drainage, sightliness, or other considerations, but wells in such situations are rarely as cheap as the less convenient wells in the hollows. Again, convenience often demands that the well be located near the house, where slops are thrown upon the ground, in the vicinity of a cesspool or privy, or near the barnyard or hogpen, while safety demands its location on high ground at a considerable distance from these and other sources of pollution.

In cases of conflicting requirements it is usually the cost which eventually determines the location, or rather it is the initial cost, for in many instances the final cost of a proper installation—if the cost of the resultant loss of health is considered—is much less than that of an improper installation although the latter may not produce actual disease.

A safe well is nearly always, in the long run, the cheapest, such a well being decidedly cheaper than the cost of medical attendance. Safety should invariably be made the first consideration instead of the last. A well should never be put down in a doubtful situation, even as a temporary makeshift, for the owner almost always waits until too late before replacing it.

SOURCES OF POLLUTION.

Open or dug wells may be polluted by material seeping through the ground and curbing or entering from the top of the well. Of the seepage materials cesspools and privies are the most important source. In most localities the large amount of liquid reaching such recep-

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tacles is rapidly absorbed by the earth and becomes a part of the water body feeding the wells. Slops thrown on the surface likewise soak into the ground, and even if the liquid at first evaporates the residue is later taken up by the rain which sinks into the ground, and is carried downward to the ground-water body. The matter leached from hen yards, from hogpens, and from the manure piles near barns, eventually enters the ground and finds its way in one form or another to the ground water below. Drainage from manured fields and from pastures occupied by stock may also be a prominent source of pollution. Much of the polluted water from such sources is purified by passage through the ground and the danger of pollution of well waters by seepage is commonly exaggerated, yet gross carelessness in locations of wells near privies, cesspools, drainpipes and other filth receptacles is prevalent in many farm districts.

One of the greatest sources of pollution for farm wells is the entrance of material at the top, and dug wells are especially liable to contamination of this sort, though other well types are not entirely exempt.

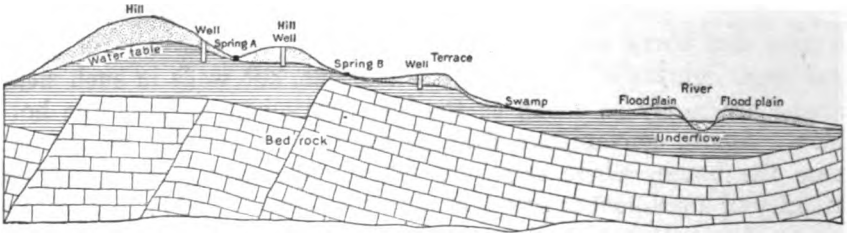

FIGURE 17.—Section showing relation of water table to surface irregularities.

Of the material entering a well from the open top dust is an important source of contamination. It is always present in the air and the amount actually settling is very many times more than the conspicuous dust coatings collecting in buildings. In fact, in open wells, especially in regions where brisk winds are common, the accumulations sometimes amount to several inches in a year. Many wells which are cleaned only once in two years are found to contain as much as 6 inches of foul-smelling black muck, representing the dust and other refuse entering the well in that length of time.

Small animals, such as toads, mice, moles, and snakes, fall into the well in times of drought when the sources of water they usually depend on have failed.

Except that it keeps the larger animals out and is a convenience in using the well, the ordinary plank covering affords but little improvement over the open well. Crevices almost invariably exist through which the smaller animals may find access, and the dirt washed through the cracks by the pump drippings may be almost equal to that entering through an open top. Moreover, it is a very

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dangerous type of dirt, as in many places it includes filth from domestic fowls and from the shoes of farm hands and others coming from manured fields, hogpens, or barnyards.

MOVEMENT OF GROUND WATER.

When a well is carried downward in porous or semiporous materials, such as those in which most open wells are located, a level is soon reached, below which the ground is saturated with water (at least down to the first impervious stratum). This water body, or ground water, as it is called, has a definite upper surface, known as the water table, which conforms in general with the broader surface irregularities as shown in figure 17, but with the difference that the

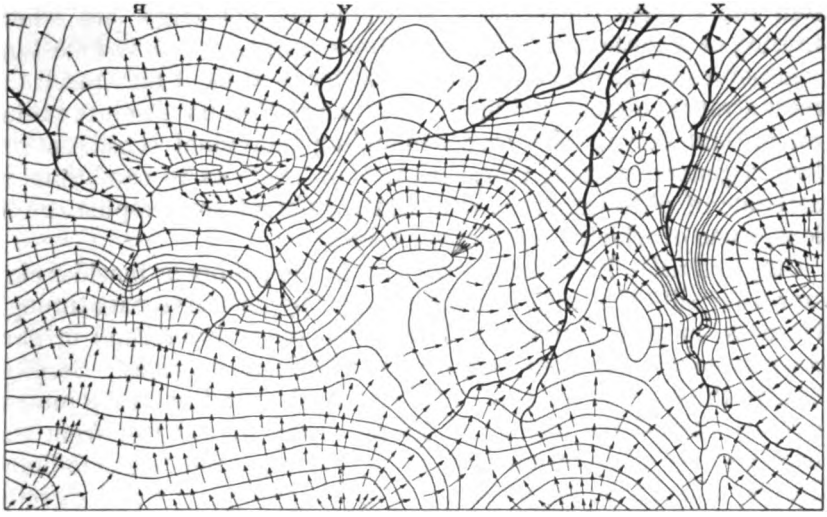

FIGURE 18.—Map showing position of water table by contours (continuous lines), lines of motion of ground water (arrows), and surface streams.

section of the water table is flatter than that of the surface, being far below the ground on hilltops and cutting the surface in valleys. The motion of the ground water is in the direction of steepest slope of the water table, as illustrated in figure 18, and as this roughly coincides with the surface slope it follows that the direction of motion of the ground water generally approximates that of the surface drainage.

From the laws of occurrence thus outlined it appears that low points are the most favorable for obtaining water by open wells, as the water movements converge in that direction and the water table is nearer the surface there than elsewhere. Sewage, being to a large extent simply water to which a certain amount of foreign polluting matter has been added, follows the same laws of motion as the ground water, converging in an identical manner toward the low spots, which are therefore points of danger where sources of contamination occur on the adjacent slopes.

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"SAFETY DISTANCE."

By "safety distance" is meant the distance from a source of pollution at which a well may be sunk with a fair degree of safety. Some writers have spoken of a "cone of safety," by which is meant an inverted conical section of earth with its apex at the bottom of the well and its base a circle of some fixed radius on the surface. The radius taken by some is the depth of the well, by others twice the depth of the well, but such limits are usually fixed without taking into consideration the nature of ground-water movements or the character of the passages in which it moves. The distance of safety also depends to a considerable degree on the quantity and concentration of the pollution entering the ground water. Where coming from the surface the amount is commonly not large, but where entering at a considerable depth, as from cesspools sunk in limestone or in porous sands which also supply water to wells, it may reach the water stratum almost undiluted. It follows that no absolute radius can be laid down, each case demanding individual consideration. Certain generalizations, however, may be made as to conditions in materials of different types and under different topographic conditions, some of which are indicated below.

Clay and till.—In ordinary clay and in the pebbly or bowlder clay known as "till" the water circulates in part by general seepage through the mass, in part through relatively thin sandy layers, and in part along more or less open but irregular tubular passages. Seepage through the body of the clay or till is very slow and polluting matter is rarely carried for any great lateral distance; 100 feet from the nearest source of pollution may perhaps be regarded as a safe limit. The clay offers even more resistance to the passage of water directly downward, a 5-foot bed as a rule effectively shutting off polluting matter from the underlying water beds, unless such matter obtains access along the break made in sinking a well or other excavation. When the water follows sandy layers the movement, though much faster than in uniform clay, is nevertheless not very rapid, rarely exceeding a few feet per day, and pollution does not often extend much over 150 feet, 200 feet usually being a safe distance. In open passages movement is much more rapid, and may amount to several hundred feet a day in extreme cases. Under such conditions there is no purification and relatively little dilution, and if the passage discharges into a well dangerous contamination may result. In a thickly inhabited region a well depending for its supply on passages of this nature is never safe.

Sand.—A bed of sand is among the safer water beds. Being of an incoherent nature, the material rarely contains open passages, the water circulating in general by a slow movement among the grains.

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The rate, though sometimes amounting to 50 feet or more a day, is usually under 5 feet and may be under 1 foot. A well 200 feet from the nearest point of pollution is probably safe in fine and medium sands, but in coarse sands and gravel a much greater distance may be essential.

Sandstone.—The movement of water in sandstone is in part through the body of the rock and in part through small open passages along the joint or bedding planes. Owing to the greater density of the rock resulting from the cementation of the grains the distance to which pollution may extend through the pores of the rock is less than in sand, 100 feet usually being a safe distance. Probably even with the water moving along the joints and bedding planes 125 to 150 feet from the source of pollution is a safe distance for a well.

Slate and shale.—In slate and shale the water follows in part the planes of stratification or bedding and in part the more or less vertical joints by which these rocks are usually cut. Unless certain of the layers are sandy the movement along the bedding planes is generally slow and pollution is carried for only short distances. The joints, however, are in many places fairly open and may conduct the water within a short time to considerable distances, possibly many hundred feet, like the granite joints described on page 15. However, unless the examination of the rock or the behavior of the drill in the well shows the presence of such open joints, a well in slate or shale may usually be considered safe if not less than 100 feet from a source of pollution.

Limestone.—The movement of water through limestone is almost entirely by means of open passages. Some of these are only a minute fraction of an inch in width, being no wider than joint and bedding planes. In such passages the movement of water is very slow and pollution is rarely carried far, 150 feet from a possible source usually being a safe distance. Other passages, however, are of considerable size, perhaps many feet in diameter, and may extend for miles. One chamber in Mammoth Cave is nearly 10 miles long, and there is evidence that similar though perhaps smaller channels exist at numerous other points. These openings are not uncommonly occupied by flowing streams which, if polluting matter is introduced, may carry it for many miles. Such streams may have connection with surface sink holes. Cornstalks and other refuse from the surface not infrequently appear in wells drawing water from limestone, and the waters are often muddy after storms. Such occurrences are indications of surface contamination and the waters should be avoided if possible.

Granite.—Practically no water passes through the body of granite, the movement being mainly along joint or fault planes or through

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pore spaces in the disintegrated upper portions of weathered granite masses. Polluting matter may reach to considerable distances through joint or fault planes, as is indicated by the fact that the salt water of the ocean finds entrance to some wells located 500 feet, and in places even a quarter of a mile or more, from the shore. It is said that in the deep public well sunk in granite at Atlanta, Ga., sufficient polluting matter entered through a joint struck at 1,160 feet from the surface to render the water unfit for drinking.

PROTECTION.

Protection from surface wash.—Many open wells are exposed to the same danger of pollution from surface wash as springs, and the same methods of protection should be used. A water-tight curb should be raised a few inches or a foot above the level of the surrounding surface and the earth banked around it, with a slope away from the well. This curb quickly deflects the water and prevents it from collecting and soaking through the ground into the well.

Protection from stock.—The chief means in which wells become polluted by stock is through seepage from the surface. Watering troughs are commonly placed close to wells, and usually in such places the hoofs of the animals soon wear holes in which the rain water and more or less of the animal excrement collect and soak into the ground, finally reaching the well. To prevent this contamination the watering trough should be placed as far away from the well as possible, the water being conducted to it by pipes. A well in an open pasture, if it is to be used at all by human beings for drinking water, should be surrounded by a fence at least 20 feet away.

Protection from pump drippings.—The drip from pumps is a very common and dangerous source of pollution. In the greater proportion of dug wells provided with pumps the well is covered with boards or planks laid or nailed over the top. No matter how carefully these platforms are constructed cracks through which water can enter almost invariably exist, and it is a common occurrence to have the water dropping or trickling back into the well whenever any is spilled in pumping. The danger of this will be understood when it is recalled that those stepping upon the platform to pump may have just come from the barnyard or from manured fields, bringing with them on their shoes more or less filth, part of which is left on the planking and washed into the well by dripping water from the pump or by the next rain. The wooden platform should be replaced by a water-tight cover made of iron, cement, or other impervious material. Cement covers are coming into use in many localities and afford ideal protection.

Protection from small animals.—An ever-present cause of pollu- in open wells and wells insufficiently protected by coverings is

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the entrance of small animals. It is a common thing for snakes, toads, mice, and even rabbits to penetrate through crevices and to fall into the well, especially in dry seasons when the animals are compelled to make desperate attempts to reach water. The remedy is an impervious well cover fitted tightly to the curb.

Protection from dust.—Dust is usually less dangerous than other sources of pollution, but in dry seasons, when dirt from the street or barnyard is being blown about, it may become of considerable amount and danger. It is not uncommon to find several inches of black, foul-smelling silt in the bottom of a well on cleaning, even though it may have been cleaned only a year or two before. The dust may be kept out by water-tight coverings such as are used to keep out pump drippings.

INCREASING THE YIELD.

The methods of increasing the yield of wells vary according to whether the well is of the dug or drilled type and whether the existing supply has or has not materially decreased from the original supply. An originally inadequate yield commonly results from insufficient supplies in the water-bearing rock or from the slowness with which the supplies are given up. A decreased yield may be due to some defect in the well itself.

Remedy for insufficient supplies.—Ordinary clay and the denser varieties of pebbly and bowlder clay or till usually contain but little water, and this little is often largely in the form of interstitial water held in the body of the material and given up slowly to a well by general seepage. Under such conditions the amount entering the well is often more or less proportional to the area of surface exposed in the wall. This area varies with the diameter of the well; thus, three times as much surface will be exposed in a given height of wall in a 6-inch well as in a 2-inch well and six times as much in a 3-foot as in a 6-inch well. To give a large yield a large-diameter well is very desirable in materials of the character mentioned.

Large wells are also desirable in rocks in which the water occurs in a similar manner—that is, in pores rather than in open passages. In general, however, if water is yielded at all by the rocks, it is given up more readily than by clays, hence a large bore is less necessary This is fortunate, for the range of size in rock wells is usually rather scant, owing to the fact that most rock wells are of the drilled type. Where the water occurs in bedding or joint planes the diameter is of still less importance, as the entrance of the water is localized and is relatively free. Large diameters, nevertheless, increase materially the likelihood of striking an opening. In the oil regions the increase of the diameter of a bore 2 inches by reaming has been known to open pools not encountered in the original hole, and a similar result is possible in water wells.

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The depth of dug wells in material in which the amount of water is relatively small is also important, for increase in depth increases the storage space in which the water can collect during periods when the well is not in use, thereby greatly adding to its total capacity.

In many regions, owing to the removal of the forests and the construction of drainage ditches, the water from rainfall and snowfall runs off more rapidly than formerly and much less sinks into the ground. As a result the ground-water level has been lowered over large areas and wells which once afforded good supplies are now dry. In many places there is still plenty of water in the ground, the only difference being that its level has sunk below the bottom of the well. In such places the deepening of the well brings complete relief.

Cleaning the well.—In the course of time an accumulation of material entering the well as dust at the top, or washed in through the ground, forms considerable amounts of silt in the bottom and on the sides. In some wells this deposit is sufficient to hinder, to a certain extent, the entrance of water into the well and to lessen its storage capacity. Some relief is usually afforded by cleaning out the well.

DEEP WELLS.

Depth is one of the most important factors to be considered in sinking a well. On it both the type and the location often depend. The benefits which the owner expects to realize from a deep well as compared to a shallow well are (1) larger supply, (2) higher head, and (3) purer water.

LOCATION.

In the location of deep wells the chief consideration is the obtaining of a supply, slight differences in location seldom seriously affecting the cost, while the prevailing use of casing in soft deposits insures safety from ordinary sources of pollution. The occurrence of deep waters depends on the character and structure of the rocks far below the surface. No indications of these features are usually found at the surface, and the well may as a rule be located independently of surface relief, though where artesian flows are expected the well should be located on as low ground as possible. Information as to the best location for a deep well may often be obtained from a careful study of the records of wells in adjacent regions, which can be made by the more experienced and intelligent drillers, or from a study of the rocks and their structure, which often requires the services of a trained geologist.

GENERAL RELATIONS.

RELATION OF SUPPLY TO DEPTH.

It is a widespread, in fact an almost universal belief that the amount of water increases with depth and that water may be had anywhere if one only "goes deep enough." This is, however, far from the

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truth. Rainfall appears to be the source of at least 99 per cent of the fresh water found in the ground, the remainder being water included in the rocks at the time of their accumulation beneath the sea, together with a small amount derived from volcanic sources. As would be expected from its atmospheric source, water actually decreases rather than increases in amount with depth, a great many rocks encountered by the deeper wells and mines, especially at depths below 1,000 feet, being entirely destitute of water.[a]

However, if only the more superficial portion of the crust is considered, there is in general an increase of water with depth. Except in valley bottoms and other depressions the surface soil and rocks, although carrying much moisture, are rarely saturated; but at depths which vary, according to climate, soils, and topography, from a few to several hundred feet, a saturated zone constituting the ground-water body is encountered. Wells starting anywhere above drainage level will in general encounter water in increasing amounts at least down to the drainage level. Again, the surface beds may be of non-porous nature and may therefore be destitute of water, while the underlying beds, if porous and below drainage level, are likely to be saturated.

Of course there is a constant tendency for the surface waters to penetrate downward and fill the porous rocks below. That these are at present destitute of water may be due, at least in certain rugged regions, to the draining of the deeper and in places relatively porous beds by deep valleys. Elsewhere, and this is doubtless the most common cause, the water is kept from percolating downward by impervious beds near the surface. The deeper rocks are largely of the granitic type and hold but little water. Except where they constitute the surface rock and are somewhat broken by joints it is of little use to penetrate them in search of water.

To speak broadly, it may be said that there is no general increase of water with depth and that the finding of deep supplies is entirely dependent on local geologic conditions. Unless there is some proof that deep water-bearing beds exist, the sinking of a deep well should be regarded wholly in the light of an experiment, although in sedimentary rocks it has the decided advantage that it may penetrate a number of water strata, which may afford in the aggregate a fair supply where a single stratum might not suffice.

RELATION OF HEAD TO DEPTH.

As with regard to volume, there is a general belief that the head of water increases progressively with depth. This belief has a better basis than the other, for in some places such a relation of head to

[a] Fuller, M. L., Total amount of free water in the earth's crust: Water-Supply Paper U. S. Geol. Survey No. 160, 1906, pp. 64-70.

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depth exists, as in the artesian system shown in figure 19, in which the deeper beds outcrop at successively higher levels.

The reverse condition is shown in figure 20. Such conditions are not the result of universally prevalent structures, although it is perhaps more common than otherwise that the strata are higher at the rims than they are at the centers of the great structural troughs. In many structural basins, the outcropping beds of the rims in fact lie high up on the flanks of mountains, while the beds of the center constitute low plains.

RELATION OF QUALITY TO DEPTH.

Another prevailing idea is that the deeper waters are purer. Within limitations this is generally true as regards the shallower waters, which, being close to the surface and without the protection afforded by overlying clays or other impervious beds, are susceptible to pollution. Deeper waters, on the other hand, are almost always overlain by relatively impervious beds that serve to keep out polluting

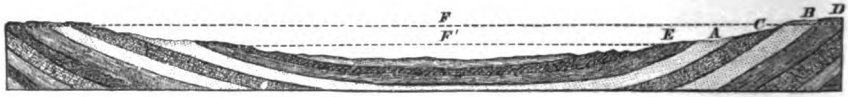

FIGURE 19.—Artesian system showing progressively higher outcrop of deeper beds.

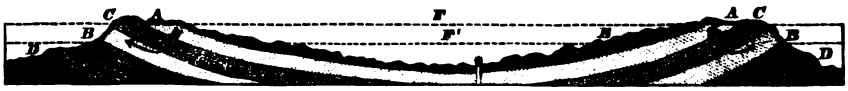

FIGURE 20.—Artesian system showing progressively lower outcrop of deeper beds.

materials, and as a rule they are entirely safe. In many places, however, the amount of mineral matter dissolved in the water shows a general increase with depth, the amount in deep waters averaging several times that in surface waters, which are largely made up of recent rainfall. There are some exceptions to this law, due mainly to variations in the character of the materials in which the waters are found, the waters in a calcareous glacial drift or in an alkaline flat, for instance, often being very much harder than those in underlying beds. Limestone waters, too, are generally harder than sandstone waters. The maxim of certain drillers, "The harder the rock the harder the water," is based on the prevailing softness of the sandstones in many districts as compared to the hardness of the limestones.

In addition to the impervious beds mentioned, the casing plays an important part in preventing the access of pollution to deep waters. When the casing has been corroded, pollution from sources near the surface is often admitted through the minute holes eaten in the iron, spoiling the deep waters. Where the casing does not entirely fill the

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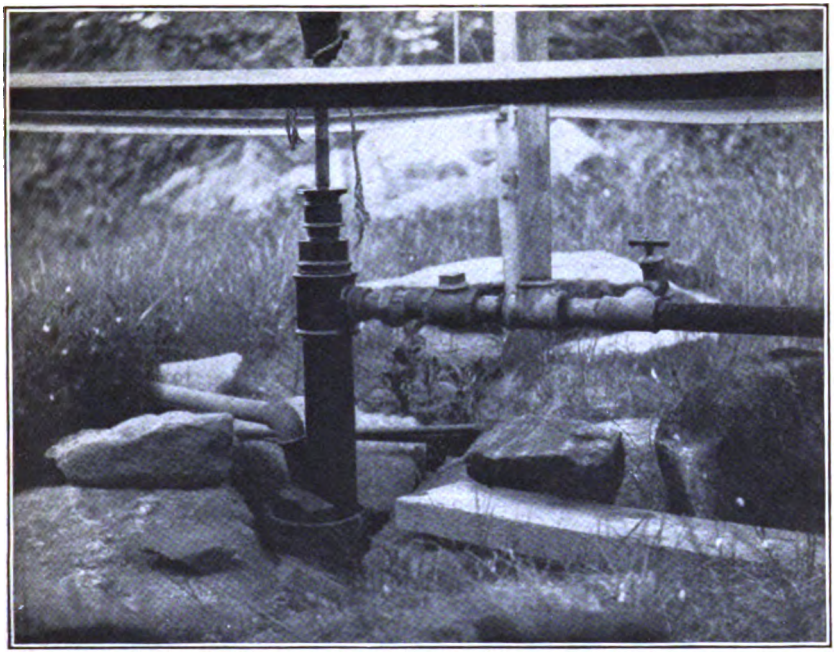

A. DRILLED WELL WITH OPENING BETWEEN OUTER CASING AND PUMP TUBE UNPROTECTED.

B. DRILLED WELL WITH OPENING AROUND CASING PROTECTED BY CEMENT.

PROTECTION OF WELLS.

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hole, contamination may pass down outside of it, while in uncased rock wells pollution may enter through any of the numerous fissures that usually exist in the upper part of the rocks. Even in such wells, however, the danger of contamination decreases rapidly with depth.

SUMMARY OF CONCLUSIONS AS TO DEPTH.

Contrary to the common belief, there is no general increase in the volume of underground water with increase in depth, such gain in volume as is occasionally found being due to peculiar local conditions. Neither is there a universal increase of head, although it may happen because the lower beds outcrop at higher altitudes than the upper ones (fig. 19). The deeper waters, however, are generally purer than those near the surface, although their mineral content is likely to be higher.

PROTECTION OF WELLS.

NONFLOWING WELLS.

Many of the conditions favorable to pollution of the shallow wells likewise favor the contamination of deep wells, but as the causes and remedies have already been discussed, especially in connection with the section on "Safety distance" (pp. 42–44) they do not require further consideration at this point.

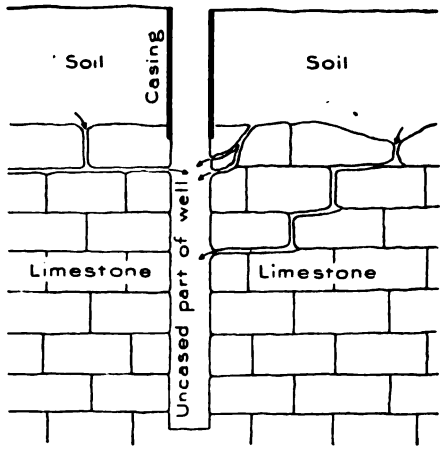

FIGURE 21.—Diagram showing danger of pollution where casing is carried only to rock.

The water of deep wells when first encountered is usually safe and rightfully has a good reputation, so that people often go to great expense in drilling for deep rock waters. Unfortunately, however, many fail to realize that unless care is taken, it is possible for deep wells to become polluted by the entrance of surface waters. In regions where the rock is within a few feet of the surface, for instance, the casing may be carried only to the rock, the fact that pollution can enter the well through the rock crevices being entirely overlooked. (See fig. 21.) The chief precaution necessary against this danger is to carry the casing to a sufficient depth to shut off all surface waters entering through fissures. It is hard to say how deep it must be carried to remove all danger of contamination, but the crevices are usually limited to the upper part of the rock (fig. 21),

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and every additional foot of casing gives additional safety. Ten feet of casing in the rock would materially reduce the danger, while 25 feet would in most wells probably insure safety. The best plan, however, is to carry the casing from the surface down to the water-bearing seam. The casing should always be set with a tight joint at the bottom to prevent the entrance into the well of surface waters that find their way downward along the outside of the pipe.

Again, it is not unusual to drill new wells in the bottom of old dug wells and to allow the polluted surface waters to mingle with the pure rock waters.

Many towns situated on rock surfaces and using unprotected wells of the type mentioned have been visited by epidemics of typhoid fever, cholera, and other diseases, leading to the loss of many lives.

Another source of pollution, less common and possibly less dangerous than the preceding, arises from the fact that many casings are left open at the top, even when care has been taken to carry them to proper depths. Plate XVI, *A*, shows a good example of this kind, there being a considerable open space between the outer casing and the inner pump tube through which small animals and various kinds of dirt find access to the water below. Plate XVI, *B*, shows a casing properly protected, all openings being hermetically sealed by cement.

A fourth and very common means of contamination of deep wells is by leaks in the casing due to imperfect joints or to corrosion. The process of corrosion may be very rapid, the pipe in some wells with acid chalybeate waters lasting only a few years. No one expects a pipe laid in the ground near the surface to last many years, yet many seem to think that a well casing will last indefinitely. Unfortunately, this is far from true.

The detection of leaks is somewhat difficult. In some wells, however, water may be heard trickling in or may be seen by a light ray projected down the well by a mirror when the pump is withdrawn. The admixture of water from outside sources may sometimes be detected by a difference of the hardness of the well water, by an earthy taste or taste of decayed vegetation, or by a cloudiness due to silt brought in by superficial waters.

The remedy is usually to pull the old casing and replace it by a new one, the length of time the pipe is allowed to remain before replacement being determined by an estimate of its life based on the action of the water on the pump tube or other pipes. An alternative treatment sometimes employed when the leak is near the surface is to set a packer designed for the purpose in the space between the bottom of the pump tube and the casing and fill the space above with cement.

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FLOWING WELLS.

In order that water may have sufficient head to flow out upon the surface it must be confined under some impervious or relatively impervious clay or other bed. This effectually shuts out pollution from the overlying material, and any contamination that reaches the well must be transmitted laterally for relatively long distances. As pollution rarely extends through the ground to any great lateral distance from its source, it follows that artesian waters are almost never polluted.

In artesian wells the water, being under greater head than that in the surrounding materials, will pass outward through any leak that may develop rather than admit the water of lower head to the well. Suction, such as is developed in the Richards apparatus in laboratories, which might be conceived as drawing in outside water through openings in the casings, can not take place with the relatively low velocities of the water in the ordinary artesian wells. Even in a well in which the water has a very high velocity, the suction is so slight in proportion to the immense volume discharged that it may usually be neglected

INCREASING THE YIELD.

METHODS OF INCREASING ORIGINAL YIELD.

Shooting.—The practice of "shooting"—exploding a charge of nitroglycerine or other explosive in a well—has long been successfully employed in the oil regions and has in late years been used to increase the flow of water wells, in which dynamite is more commonly used. The action of the dynamite is to shatter the surrounding rock, with the result that connection is frequently established with other crevices, in some wells largely increasing the water supply. (See fig. 22.) The dynamite is most effective in hard, brittle rocks, such as limestone, which are as a rule completely shattered by the explosion, and is least effective in soft tough shales, which are bent and compressed rather than broken.

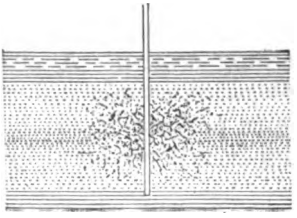

FIGURE 22.—Diagram showing loosening effect of shooting wells.

Steam jet.—Shooting, owing to the character of the materials, is not usually practiced in unconsolidated deposits, in which the steam jet is sometimes used instead of dynamite. The steam is forced down a small pipe inside of a larger one and coming into contact with the water at the bottom turns it quickly into steam, the resulting explosion loosening the material or making a pocket about the bottom of the pipe. Where the materials are dense and clayey, the action of the steam jet may considerably increase the influx of water; in the more porous deposits it has less effect.

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Packing with gravel or sand.—It frequently happens that where the material is very fine it packs around the well so as to hinder the entrance of water. In such cases it is a common practice to drop a supply of pebbles into the well and with the aid of a drill force them out into the surrounding clay, etc., until a pocket of pebbles is produced through which the water flows freely to the well.

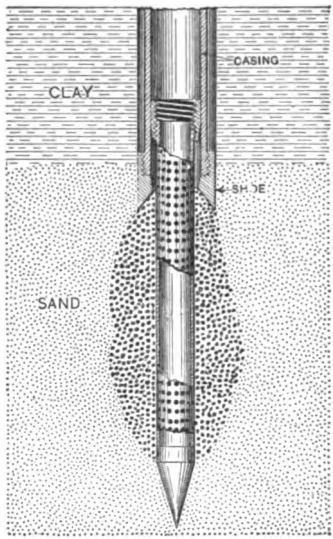

FIGURE 23.—Diagram showing formation of sand packing through pumping.

In quicksands, the space between the outer casing and the pump tube and strainer is often filled with sand through the heavy suction induced by pumping. This sand in many wells keeps back the quicksand while allowing the water to pass through it freely and to enter the well. (See fig. 23.)

Production of sand or other pockets by pumping.—Many of the materials yielding water to wells consist of mixtures of sand or gravel and clay. By heavily pumping a new well it is often possible to remove the fine clayey material, leaving the sand grains and pebbles in a sort of pocket about the well (fig. 24), the result being much like that produced by the artificial gravel pocket described in the preceding section. A similar method is employed in certain stiff clays, in which small open pockets at the bottom of the well are apparently produced by the heavy pumping.

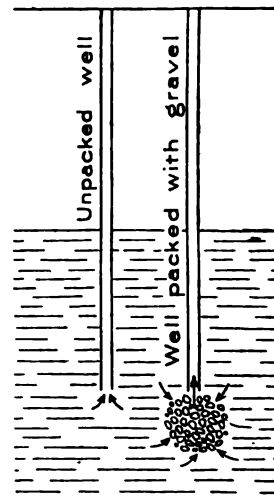

FIGURE 24.—Diagram showing advantages of packing with sand and gravel.

METHODS OF RESTORING LOST SUPPLIES.

When a deep well is first sunk, it usually gives good supplies, but as time elapses the yield is found to decrease gradually until finally it is but a small fraction of its original amount. This decrease is commonly attributed to a decrease in the general supply of the region or to the drawing off of the water by newer and better wells. In many wells this is a real cause, but in others the failure is due rather to the deterioration of the old well than to the losses caused by new wells, which in reality have a large yield simply because they are new and in good condition. The chief causes of decrease or failure are clogging of the screen, entrance of sand, and leakage.

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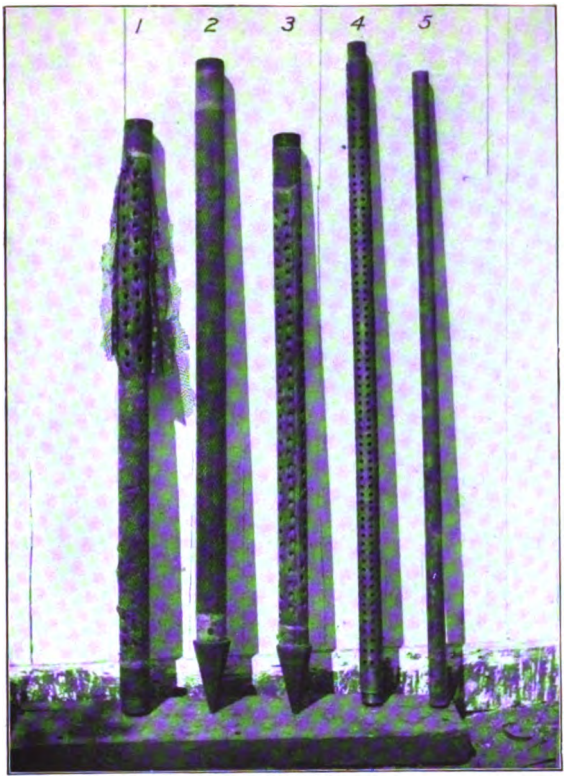
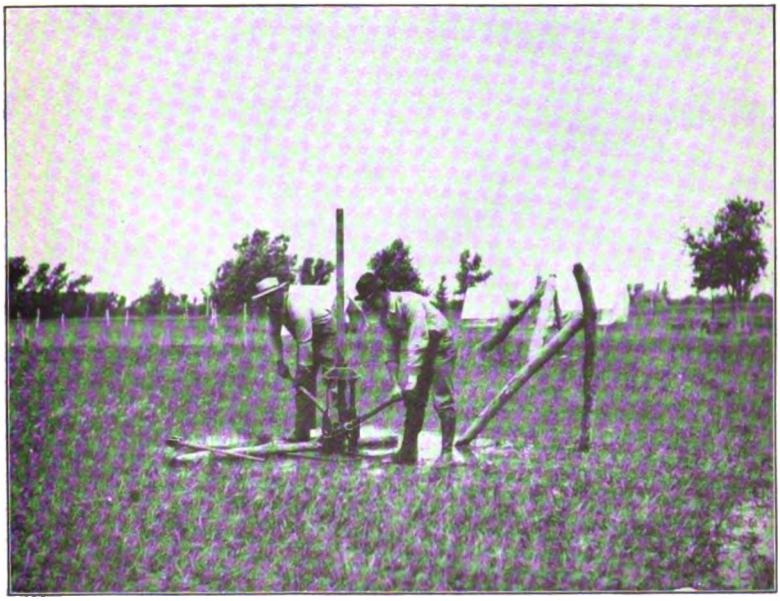


A. WELL POINTS.



B. PULLING PIPE WITH JACK.

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Rescreening the well.—Of the causes of failure enumerated the clogging of the screen or strainer is probably the most common. This may result from the filling of the perforations by sand and silt sucked in with the water, but other very common causes are the closing of the pores by the deposition of iron or lime. Where the waters carry acids in solution, the screen is often attacked and corroded, the iron set free being redeposited in the sand about the screen, forming thick, impervious coatings of a sort of sandstone which sooner or later effectually shuts off the water.

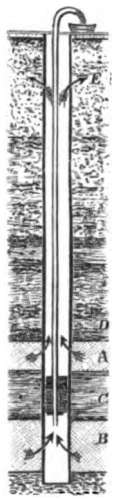

FIGURE 25.—Section of well showing loss by leakage into the superficial deposits. (After Chamberlin.)

When the matter collected about the well point is soft and loose, it can often be removed by back pressure produced by pumping heavily into the well, the outward current forcing back the accumulated silts. When this fails, the usual remedy is to pull the casing and screen, or the pump and well point, and replace it by a new one. (See Pl. XVII.)

FIGURE 26.—Section of well showing loss by leakage from one deep bed into another. (After Chamberlin.)

Prevention of the entrance of sand.—If a well is not properly constructed or screened, sand or quicksand may enter the well in large quantities and greatly hinder the entrance of water. In some wells this is remedied by substituting a finer screen, and in others by packing gravel about the bottom of the well, or around the screen or strainer, as already described. The packing of sand about the strainer has enabled many wells to draw on quicksands that ordinarily would have almost immediately choked and ruined the wells.

Prevention of leakage.—Leakage in wells affording acid waters is very prevalent, the pipes becoming rapidly corroded until holes appear in their walls through which the water from the well may escape. The only way to prevent leakage of this type is to recase the well.

In uncased wells there is much leakage into other non-saturated beds, as is clearly shown by the accompanying diagrams (figs. 25 and 26). Figure 25 shows the water from two deep-lying beds being lost into one near the surface, and figure 26 shows a loss from one deep bed into another. The remedy for either condition is to carry the casing down to the principal water bed and not try to draw on two beds of different heads.

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CISTERNS.

The ordinary cistern is an excavation in the ground, usually circular in shape, lined with a supposedly impervious coating of cement or other material, and used for the storage of rain water. Cisterns are used chiefly where the supply of well water is insufficient or its quality objectionable.

ADVANTAGES OF CISTERNS.

Supplementary supplies.—In many of the best farming regions of the country, as in the Blue Grass region of Kentucky and elsewhere, the rocks either carry so little water or carry it so irregularly that many wells fail to obtain a sufficient supply to meet domestic needs and the demands of stock. In shaly regions the water supplies are even more uncertain and it is often impossible to procure the necessary supplies from wells. This is true also of many areas underlain by clay and of some areas characterized by thick beds of clayey till. In all these regions supplementary supplies of water are necessary, at least for stock, and where springs, ponds, or lakes are not available cisterns must be resorted to, and in some places they are necessary even for domestic supplies.

Softer and fresher water.—Rain water is the softest of all natural waters, hence is very desirable for washing and other domestic purposes, especially in limestone regions, where the water of many wells or springs is so hard that soap, instead of dissolving and making a good lather, forms a dirty-looking curdle or scum on the surface. In such regions much trouble is also caused by the formation of thick crusts of lime and magnesia on the inside of the kettles and other utensils and by the precipitation of the white, milky sediment which clouds the water when it has been boiled. In other regions, as in the Atlantic Coastal Plain, the water may be highly charged with soda, with the result that rice or other white foods cooked in it are turned a dirty yellow. Elsewhere, especially on low sandy beaches and the keys of our limestone coasts, the well water is brackish and unfit for drinking. All these difficulties are avoided if soft cistern water derived from the collection of the rain water is available.

Safety.—It is usually impossible for pollution to enter a properly constructed cistern—one in which the lining is water-tight—through the walls, and with a little care and by providing water-tight covers it is possible to keep out much of the undesirable matter from the top. Of course more or less dirt may be washed from the roof into the cistern, but the first run-off can be allowed to waste either by some automatic appliance or by hand, letting only the later and relatively pure water enter the cistern. A cistern, therefore, if properly made and cared for, is to be regarded as a practically safe source

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of supply. It is certainly far safer than the ordinary dug, bored, and punched well, and even than many of the shallower driven wells.

Convenience.—Another great advantage of a cistern is its convenience. As they are built near or even under a house, dairy, or barn, the water may often be pumped directly from them to the sink or to the dairy or watering trough.

Ease of cleaning.—Because of their shallowness and the smoothness of their walls cisterns can be much more quickly and thoroughly cleaned than wells. Consequently they are usually cleaned more frequently and the water is kept in better condition.

DISADVANTAGES OF CISTERNS.

Contamination by dirt from roof.—The dirt from the roofs is very objectionable, including dust blown from barnyards and highways, the droppings of birds, etc. The remedy is, as already stated, to allow only that portion of the water falling during the latter part of a shower, after the dirt from the roof has been largely removed, to enter the cistern.

Liability to crack and admit pollution.—The greatest disadvantage of a cistern and one which subjects the users to grave danger is the liability to crack. No matter how good the cement used in the construction or how careful the workmanship, cracks are liable to develop and admit shallow and possibly polluted ground waters. It is to the waters entering in this way that the notable hardness often indicated in cistern waters is due. Cistern water under normal conditions is soft, and if it becomes hard it is a sure indication that ground water has in some way found access to the cistern. It is a danger signal which should not be disregarded, and whenever it is noted the cistern should be emptied and repaired at once.

CONDITIONS UNDER WHICH CISTERNS ARE DESIRABLE.

Cisterns are desirable (1) wherever the rock, clay, or other materials in which the well is sunk are poor water bearers; (2) wherever the ground water is too hard for washing, too alkaline for cooking, or too brackish for drinking; and (3) wherever waters from other sources are inherently unsafe. They are especially desirable in the larger towns where the houses are crowded and the wells often polluted, and where no public supply is available. Again, on farms, where wells are not infrequently located near barns or other sources of pollution, cisterns often constitute the only safe source of water.

SIZE.

The ordinary cistern, usually 5 or 6 feet in width and 10 or 12 feet deep, almost invariably fails to meet the demands on it during extended periods of drought. To insure a supply which can always

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be depended on either for domestic or for stock use, much larger cisterns are necessary.

If rainfall were equally distributed throughout the year and if the consumption of water were regular, a cistern large enough to hold one or two months' supply would be sufficient, but, unfortunately, the rainfall is ordinarily very irregular, from one-half to two-thirds of the entire precipitation of the year not infrequently falling in three or four of the colder months, while the remainder is distributed over the eight or nine warmer months. This reason alone would make large cisterns desirable, but still another reason is found in the larger consumption of water in the warmer season, which is generally the period of deficient rainfall. To be sure of a supply through long periods of drought such as are likely to occur one or more times in each decade, it is necessary to have a cistern that will hold when full two-thirds or three-fourths of the total amount required during the year. For drinking, cooking, and washing each person on a farm ordinarily uses from 5 to 10 gallons or more of water a day, and each head of stock ordinarily requires from 6 to 15 gallons. The amount used, however, depends so largely on local conditions that it should be carefully ascertained in each specific case before the size of a cistern is determined. An allowance of 25 to 35 per cent should also be made for loss due to the deflection of the earlier and more or less dirty washings from the roof, the overflow of gutters in heavy storms, the loss by snow sliding or blowing from the roof, the leakage of pipes, and other minor causes. The total amount needed and the allowance for loss having been determined, it becomes possible to calculate the size of cistern required. The volume of a round cistern is approximately five-sixths of the product obtained by multiplying the square of the diameter by the depth.

For assistance in determining the amount of water annually falling on a roof the following table, showing the number of gallons falling on each square foot on roofs of gentle, medium, and steep slope at different rates of rainfall, is presented. The annual rainfall of any particular locality can be ascertained from the United States Weather Bureau.

Amount of water falling annually on roofs of varying slopes at different rates of rainfall.

Slope of roof.		Water falling on roof, in gallons per square foot, when annual rainfall, in inches, is—									
Degrees.	Ratio (vertical to horizontal).	15	20	25	30	35	40	45	50	55	60
45	1:1	6.6	8.8	11.0	13.2	15.4	17.6	19.8	22.0	24.2	26.4
26½	1:2	8.3	11.8	14.8	17.7	20.7	23.6	26.6	29.5	32.5	35.4
63½	2:1	4.2	5.6	7.0	8.3	9.7	11.1	12.5	13.9	15.3	16.7

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LOCATION.

Theoretically the location of a cistern makes little difference in its liability to pollution, but practically it is of the greatest importance. As has been indicated, cracks in the walls are of common occurrence, in some cisterns being sufficiently open to admit enough outside water to make the supply noticeably hard, and where such water can enter pollution can enter also. Bacteria or disease germs can develop in substances which can not be filtered from the water and it is entirely possible for pollution by such means to enter the cistern through cement walls even when there are no cracks. It is therefore highly desirable that the cistern should not be located near a sewage drain, barnyard, or other source of contamination, the same precautions being observed as have been indicated for wells (pp. 44–45). The site selected should be in firm ground, as otherwise there will be danger of the cistern settling and cracking. Roots of trees are also a frequent cause of injury, and cisterns should be located as far away from them as possible.

CONSTRUCTION.

The excavation should be made large enough and deep enough to permit the laying of proper foundations and adequate walls. For curbing either stone or brick laid in mortar and cemented on the inside with a thick coating of hydraulic cement may be used. It is preferable that the top be arched over with brick or stone and lined with cement. An opening, provided with an air-tight cover, through which a person may enter the cistern for purposes of examination, cleaning, and repair, should be left at the top. After the completion of the cistern, it should be frequently examined, in order to detect and remedy any cracks or other defects due to settling, the action of frost, penetration of tree roots, etc.

COMBINATION WELLS AND CISTERNS.

Although cisterns of the dimensions indicated in the preceding section will supply enough water for domestic use in a small family, they will not supply enough for stock. In fact, unless the farm buildings are very large or numerous it is, as a rule, impracticable to procure enough cistern water to supply more than a few head of stock, and it is therefore generally necessary to utilize the ground-water supplies. These are sometimes too far from the surface to be available during the summer, but there is almost always enough water in the ground in winter, and the ideal provision would be to store a portion of the winter supply for summer use.

In the winter the ground-water level is high, often standing only a few feet below the surface, but in summer it is usually much lower, often many feet from the top of the ground. If a well is carried deep

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enough, sufficient water can in most places be obtained, but many wells are too shallow to give never-failing supplies, and as a consequence they may be short of water in times of drought. If the water in the well in the winter could be retained till summer, there would be little difficulty with the supply of most wells, but, unfortunately, as the ground-water level falls the water in the wells falls also. In figure 27 *ac* indicates the depth of water in a well during the winter, and *bc* indicates its depth in the summer when the water level is at *b*. The volume at depth *ac* might be sufficient for the whole year, and that at depth *bc* insufficient to last through the summer. To preserve the winter supply it is necessary to cement the bottom and walls of the well nearly to the winter water level, as shown by the heavy lines in the figure, thus converting it into a semicistern. When this is done the well will fill during the winter to the level *a* and will still contain water to about the level *d* after the ground water has fallen to *b*.

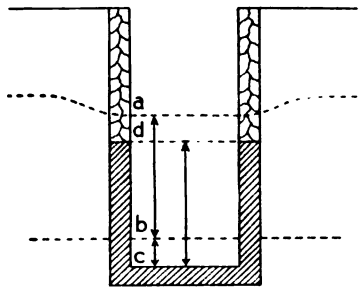

FIGURE 27.—Combination well and cistern.

Combination wells and cisterns of this type are especially dangerous if near any source of pollution, hence they are recommended only for stock wells located at some distance from buildings and barnyards. They should be used for domestic supplies only where on higher ground and at some distance from any source of pollution. Cisterns completely cemented and covered are safest where buildings are near.

In some places it is the practice to turn the water from buildings into a well, but, although the well water is somewhat softened thereby, there is no gain in amount, as water will not stand in an ordinary well higher than in the outside ground, the equivalent of the extra water turned into the well being lost by outward percolation.

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